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HUGHES TOOL COMPANY · AIRCRAFT DIVISION

Culver City, California

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HOT CYCLE ROTOR SYSTEM FABRICATION EFFORT

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HUGHES TOOL COMPANY -- AIRCRAFT DIVISION
Culver City, California

For

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FOREWORD

This report has been prepared by Hughes Tool Company -- Aircraft Division under USAF Contract AF 33(600)-30271 "Hot Cycle Pressure Jet Rotor System", D/A Project Number 9-38-01-000, Subtask 616.

The Hot Cycle Pressure Jet Rotor System is based on a principle wherein the exhaust gases from high pressure ratio turbojet engine(s) located in the fuselage are ducted through the rotor hub and blades and are exhausted through a nozzle at the blade tips. Forces thus produced drive the rotor.

The task to be performed under the contract involved design, fabrication and test of a complete rotor. This report covers the activities involved with the fabrication effort. It fulfills the requirement of Item 5n covering work performed under Items 5a through 5m of the contract.

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SECTION I

SUMMARY

The Hot Cycle Rotor System consists of a free floating hub and three blades mounted on a shaft supported by an upper radial bearing and a lower thrust bearing. These bearings are positioned above a whirl tower (or fuselage) by a steel tubular truss structure. This report is concerned with the effort involved with the fabrication of the rotor, test machines and fabrication jigs and fixtures. Figure 1-1 shows the rotor on the tower while Figure 1-2 presents a schematic of the rotor.

Fabrication of the Hot Cycle Rotor System was generally accomplished by well-known and time-proven manufacturing methods. Early difficulties connected with the development of manufacturing methods for a few parts were resolved by advances in the state of the art for existing methods. In general therefore, the design utilizes components, fabrication and assembly methods, and processes well established in the aircraft industry. In particular, the blade is composed of many identical small parts which are fabricated on existing high production machinery. Thus the design lends itself to fabrication of service craft at an early date and with minimum effort and cost.

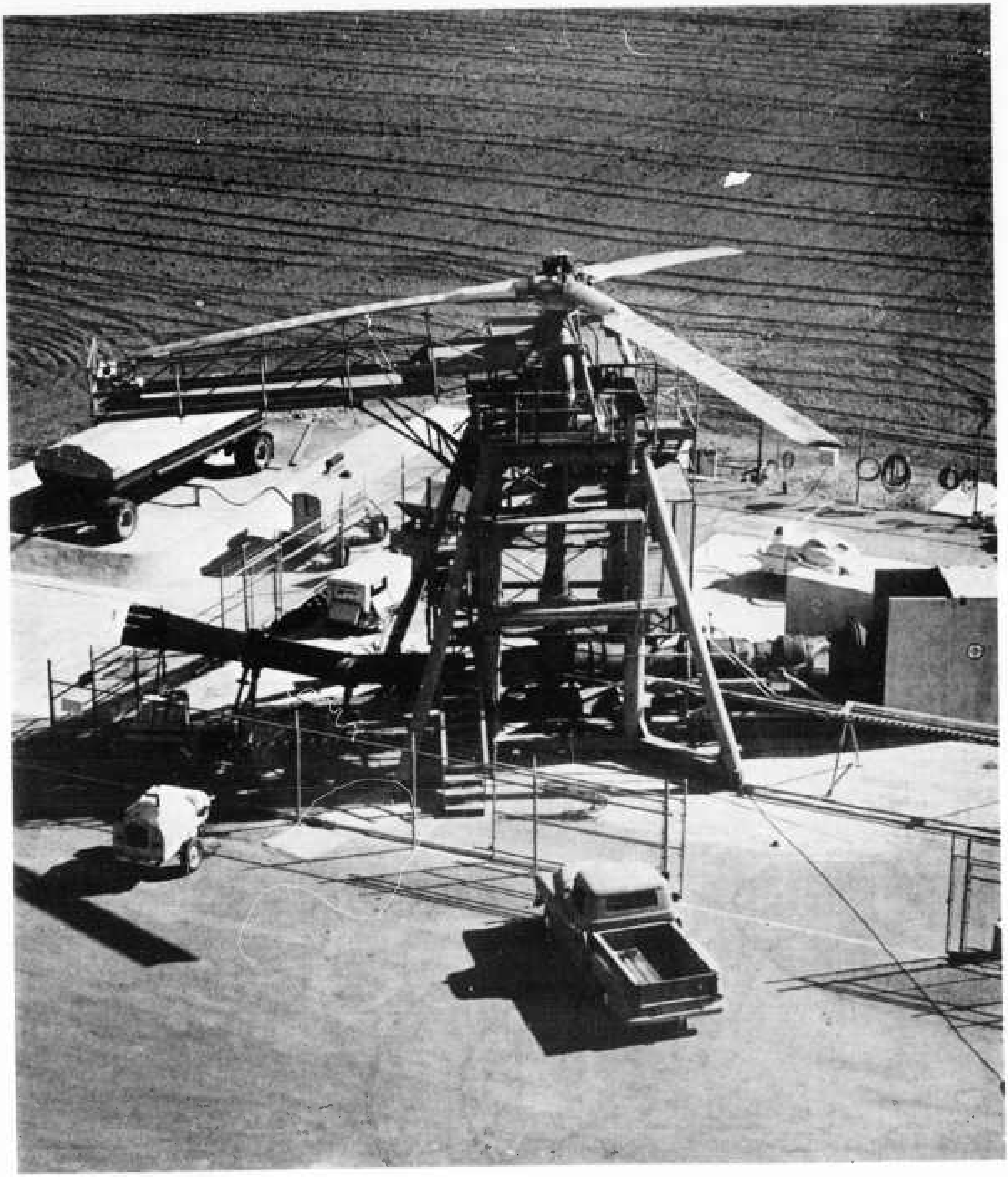

Figure 1-1. Rotor System on Whirl Test Tower

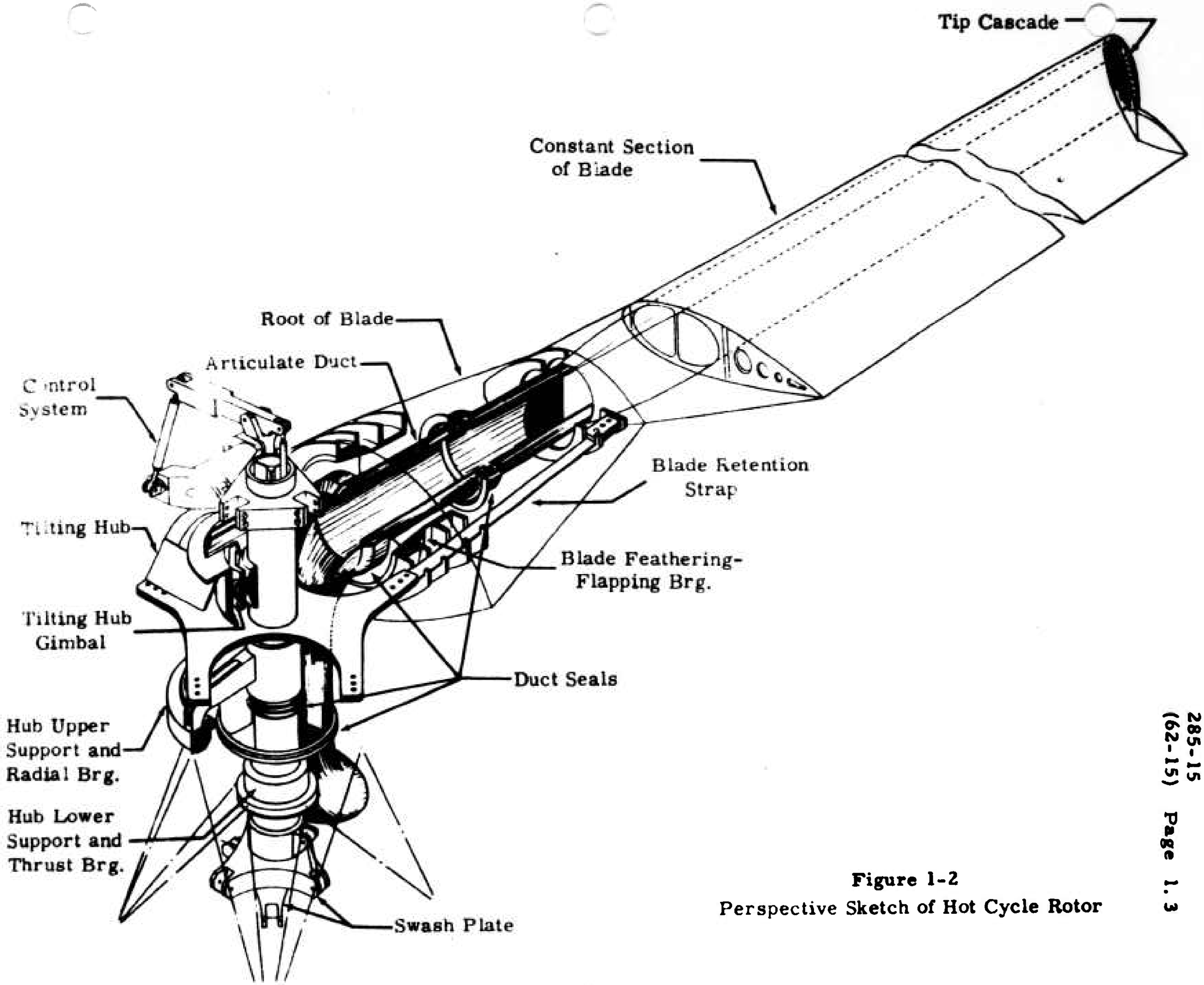

Figure 1-2
Perspective Sketch of Hot Cycle Rotor

SECTION 2

INTRODUCTION

The fact that this was an experimental program, the design philosophy as reported in Reference 1, was to utilize as far as practicable the existing manufacturing methods and to extend their application in special cases, where required. It was endeavored to avoid design which would require development of entirely new manufacturing concepts or elaborate costly fabrication equipment. Two cases which required an extension of the state of the art were the spotwelding of Rene' 41 nickel alloy and the drop-hammer forming of the blade flexures from Inconel X. Both of these processes were developed and utilized with minimum difficulty and were completely successful.

The report material following is arranged into three main sections; namely, Rotor Assembly, Test Machines, and Jigs and Fixtures. The section describing the Rotor Assembly is made up of data on details, major assemblies, and the final assembly. For an over-all view of the rotor and the whirl tower, refer to Figures 1-1 and 1-2.

SECTION 3

FABRICATION OF ROTOR

3.1 MINOR ASSEMBLIES AND DETAIL COMPONENTS

3.1.1 Blade Spars - Drawing No. 285-0170

These spars are continuous members running the full length of the blade and are approximately 26 feet long. They are machined from 6 AL-4V titanium rolled bar stock 1" x 4" in cross section and 27 feet long. It is believed these were the longest bars rolled of titanium for a specific purpose. The bar stock was ultra-sonically tested for voids and for inclusions.

The bars were machined on a long bed mill using simple clamping fixtures and good commercial practices. No difficulty was encountered. The machined spars were shot peened to increase their fatigue strength. Figure 3.1.1-1 shows the fore and aft spars ready for assembly.

3.1.2 Forward Segment Assembly - Drawing No. 285-0113

A forward segment assembly, shown in Figure 3.1.2-1, is built-up from ribs and ducts made of Rene' 41 nickel alloy, and external surfaces of 301 corrosion resistant steel.

Initially, parallel programs were conducted to join the ribs to the ducts. One method was by brazing and the other method was by spotwelding. Both methods proved successful with respect to manufacturing and performance. Spotwelding was chosen for the actual fabrication because more direct control of the procedures could be exercised. Some problems were anticipated in spotwelding of the .012 Rene' 41, for which adequate data was not available and with which experimenters had encountered considerable difficulty. However, spotwelding of this material following solution treatment was highly successful and yielded uniform spots with the strength of the parent metal. The ribs and ducts were spotwelded in the solution treated condition and then aged to increase strength of the spotweld. To avoid strain of the segment during final assembly, the spotwelding fixture used for this operation had the desired twist built into it (8° in 330 inches).

Details of the development program on the spotwelding procedures so successfully concluded are contained in Reference 2. It should be noted that it was not necessary to make a single change in the segment design as a result of the problems encountered during manufacture.

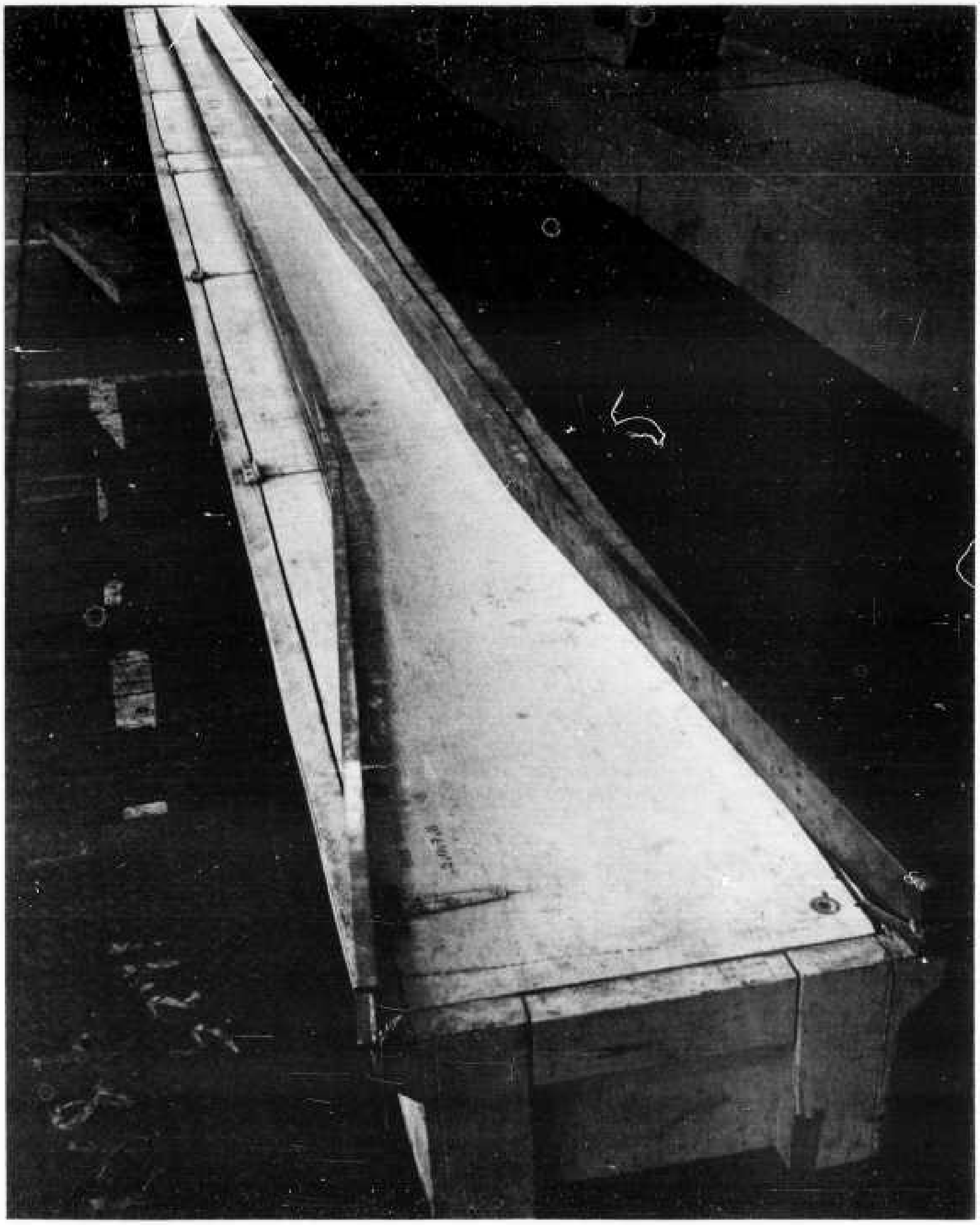

Figure 3.1.1-1. Blade Spars, Completely Machined (Titanium Alloy)

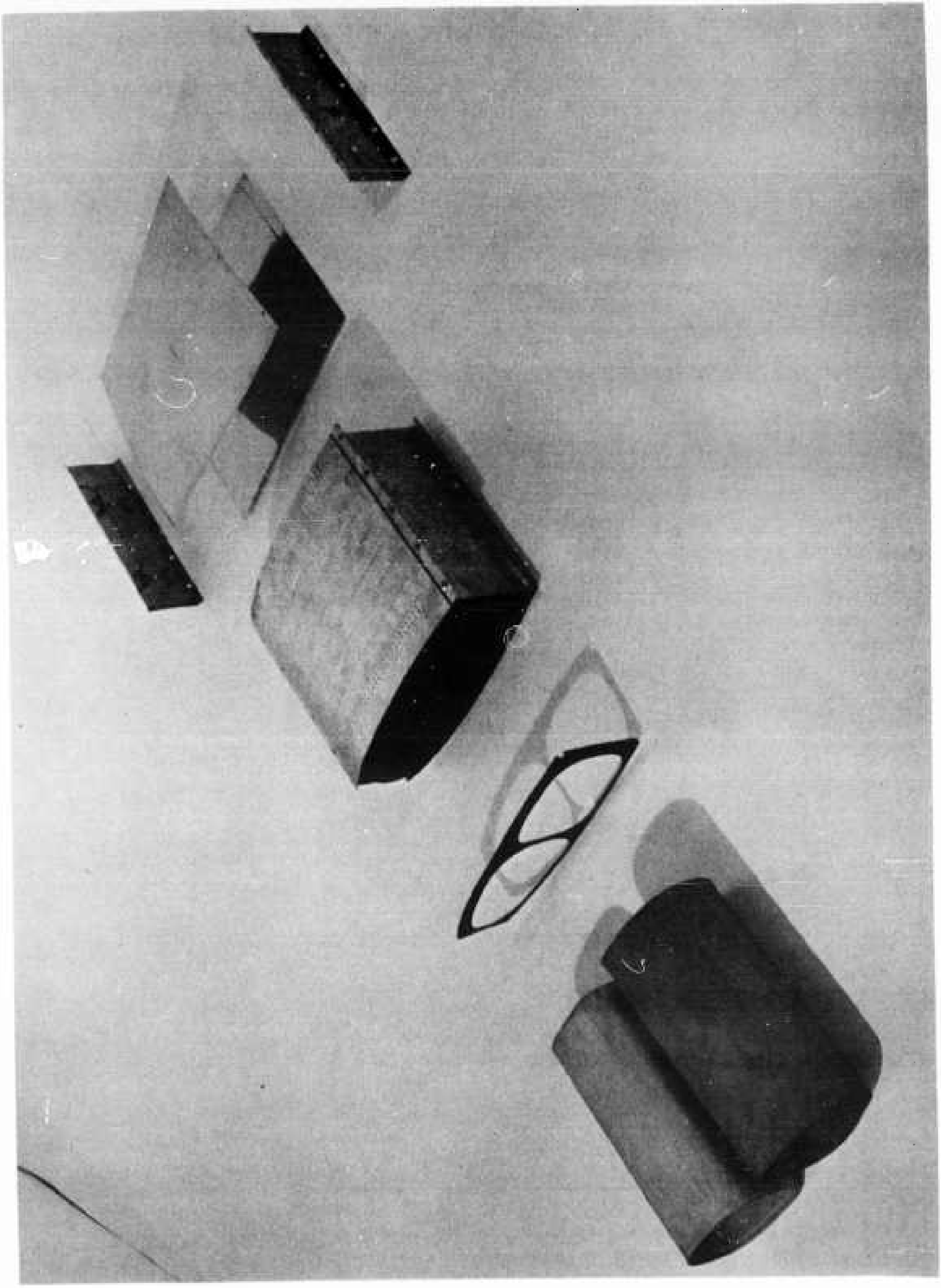

Figure 3. 1. 2-1. Blade Forward Segment and Detail Parts

3.1.2.1 The rib, Drawing No. 285-0114, for the above assembly is blanked and formed from Rene' 41 nickel alloy in the solution treated condition. Figure 3.1.2-2 shows a complete rib.

3.1.2.2 The 285-0113 -9 and -11 spanwise hot gas ducts of .012 Rene' 41 are formed in the solution treated condition. Attachment into the segment assembly is accomplished by spotwelding to the flanges of the 285-0114 rib as noted above.

3.1.2.3 The fore and aft webs, top and bottom skins are made of type 301 corrosion resistant steel, also spotwelded to the flanges of the Rene' 41 rib.

3.1.3 Blade Flexures, Coupling - Drawing Nos. 285-0165 and 285-0203

3.1.3.1 These couplings required a considerable amount of development. Originally, they were electroformed, a process which consists of making a master pattern and from that a working plaster mold, certain surfaces of which are sprayed with an electrical conductor. Metal, in this case pure nickel, is electro-deposited on the mold, and the mold broken away, leaving a thin shell of the desired contour. Following this, thicknesses are built up as desired by a series of plating operations requiring considerable skill and experience in adjustment of electrical forces and masks. Because of the combination of contour and close tolerances required, the blade flexible coupling is one to which this process seemed well suited. Nevertheless, although the techniques were worked out for the coupling, this process proved unsatisfactory from the standpoints of high cost and of low production rate. As a consequence, only nine parts made by this process have been installed in the blades. Figure 3.1.3-1 shows this part.

3.1.3.2 The coupling assembly Drawing No. 285-0203, which replaced the electroformed part occupies all stations inboard from the three most outboard positions. This coupling utilizes a flexure which has been drop hammered from .020 Inconel X in two halves and the two halves fusion welded together. This method produced quality parts at a rate compatible with the fabrication schedule which the electroforming process failed to meet. A photograph of the Inconel X drop-hammered-welded flexure is shown in Figure 3.1.3-2. The advancement of drop hammer techniques to produce a part with the complex contours and close tolerances required here is considered a breakthrough in the state of the art.

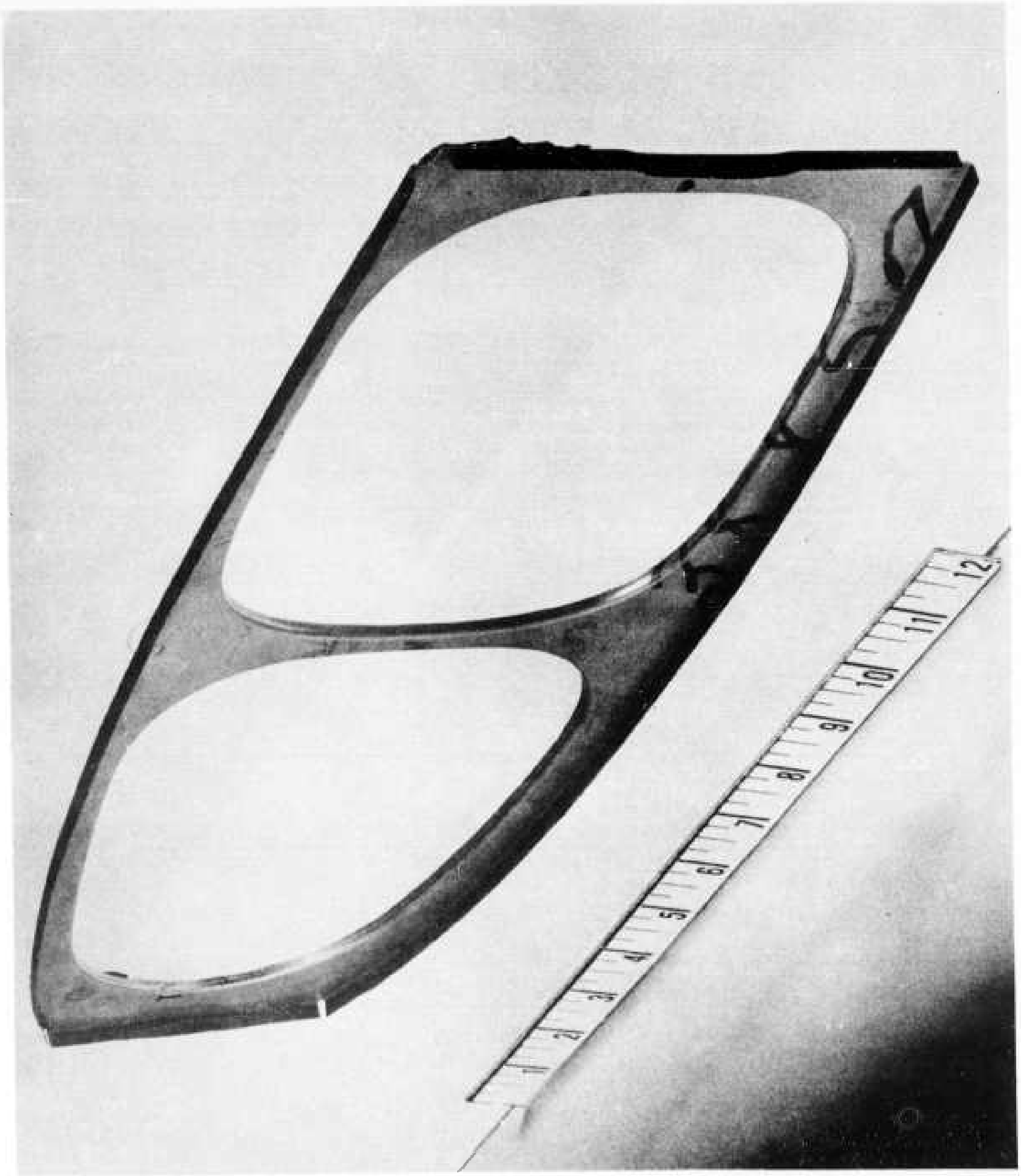

Figure 3.1.2-2. Blade Forward Segment Rib

Figure 3.1.3-1. Electroformed Flexure - Blade Constant Section

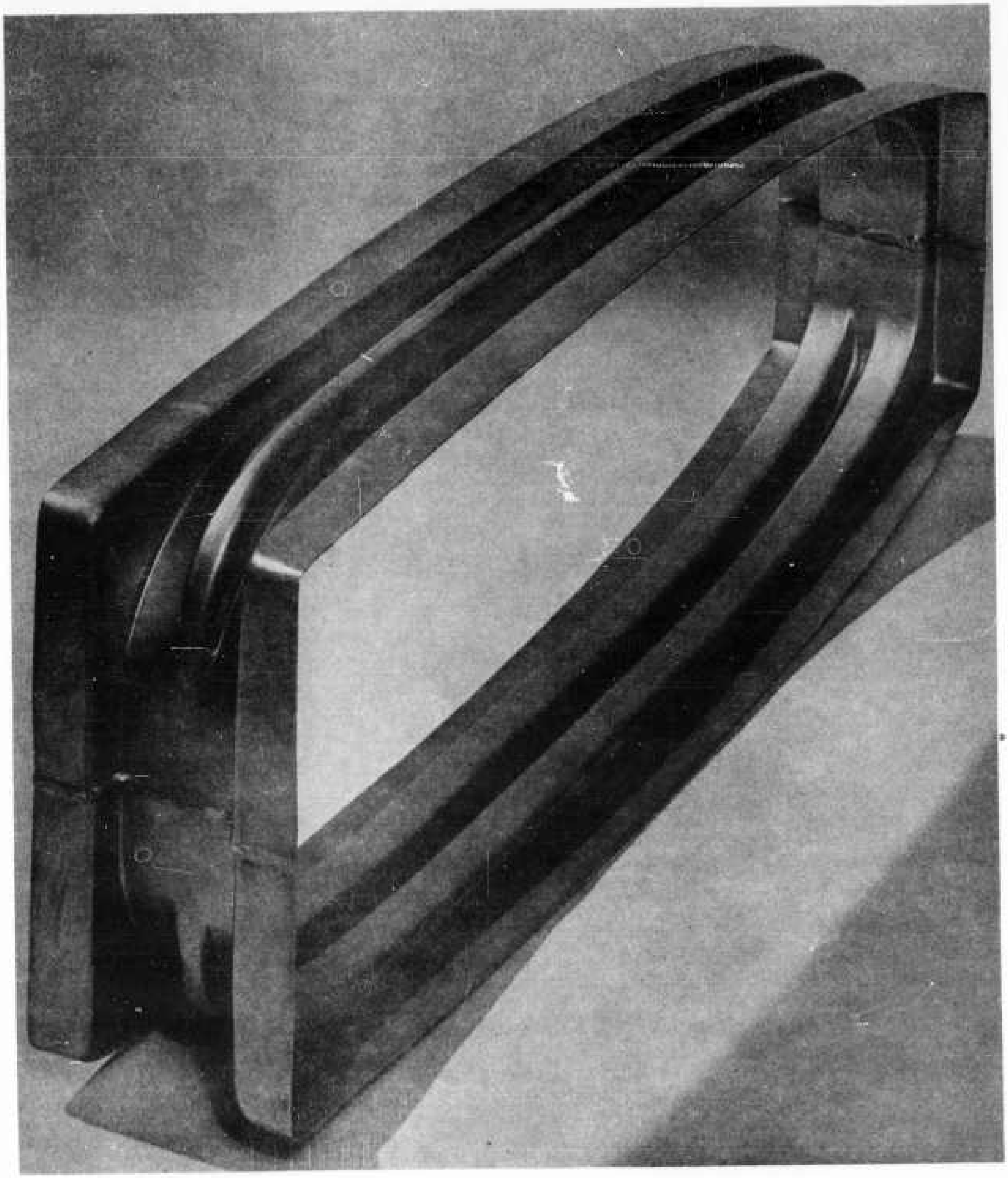

Figure 3. 1. 3-2. Drop Hammered Inconel X Flexure

3. 1. 4 **Blade Aft Segment Assembly - Drawing No. 285-0117**

This assembly forms the trailing edge of the blade and is of 2024-T3 AL (alclad aluminum alloy), anodized. Each segment has a one piece .016 thick skin, which is bonded to a web and internal ribs as shown in Figure 3. 1. 4-1. The ribs, .012 thick, were routed in stacks and formed on male and female dies.

Assembly of the aft section is by bonding with a high temperature adhesive, a method that provides smoothness of contour, simple and rapid assembly, and freedom from holes in the thin metal. As can be seen clearly in the Figure, dimpled holes were provided for attachment of these segments to the forward segments of the blade. Since dimpling of assembled skin, doubler and channel would crack the bond, it was necessary to predimple each piece individually and to coordinate the hole location.

3. 1. 5 **Blade Root Frames - Drawing No. 285-0147**

These frames are roughly rectangular in external contour, without joints, and the cross section is of hat-shape of varying depth. The frames are made of commercially pure nickel, electroformed as described for the flexural coupling. This method is particularly adapted to fabrication of parts of this variable contour in a ring configuration. Although production rate by this process proved slow, as noted in Section 3. 1. 3., it was satisfactory for the small quantity required for the test rotor. Inspection was by dye penetrant methods.

3. 1. 6 **Blade Retention Straps - Drawing No. 285-0121**

This assembly (Figure 3. 1. 6-1) absorbs all of the blade centrifugal forces; thus exceedingly stringent quality controls must be exercised with respect to machining, inspection and handling. The individual laminations are made of .025 thick type 301 full hard corrosion resistant steel with a minimum utlimate tensile strength of 185,000 psi. The laminations were milled ten at a time, and all edges were rounded to .005 -.010 radius except around holes. They were then stress relieved at $825 \pm 25^{\circ}F$ for one hour.

Following final inspection of the machining work, the entire strap, with the exception of the end was sprayed with teflon suspensoid No. 854-201, (1) cured at 725°F for five minutes. For convenience in drilling and handling, the lamination ends were bonded together with a very thin coating of adhesive to form a single strap pack. Full size bolt holes were then drilled and ground in the ends of the pack.

(1) E. I. duPont de Nemours and Co., Inc., Wilmington, Delaware

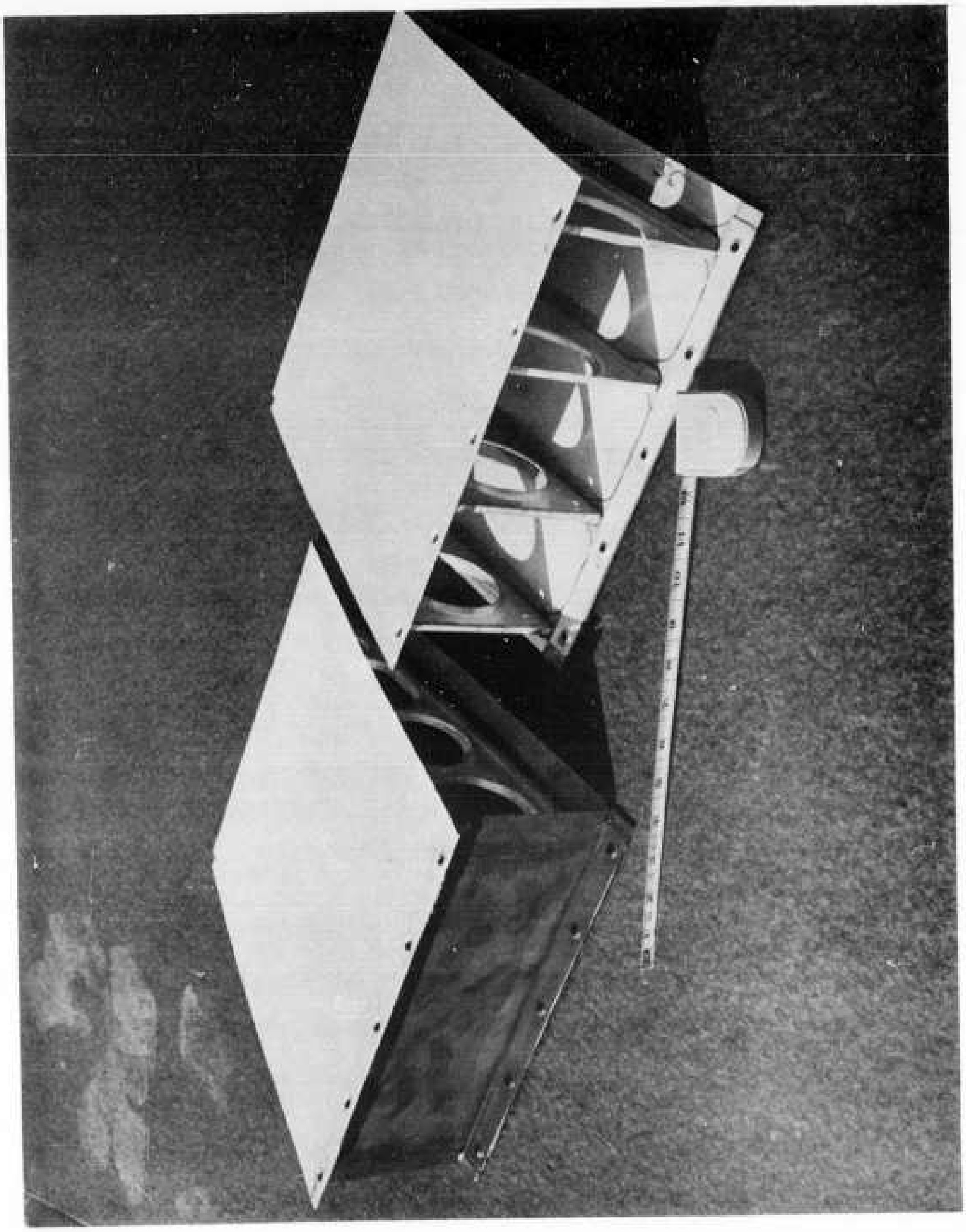

Figure 3. 1. 4-1. Blade Constant Section Aft (Trailing Edge) Segments

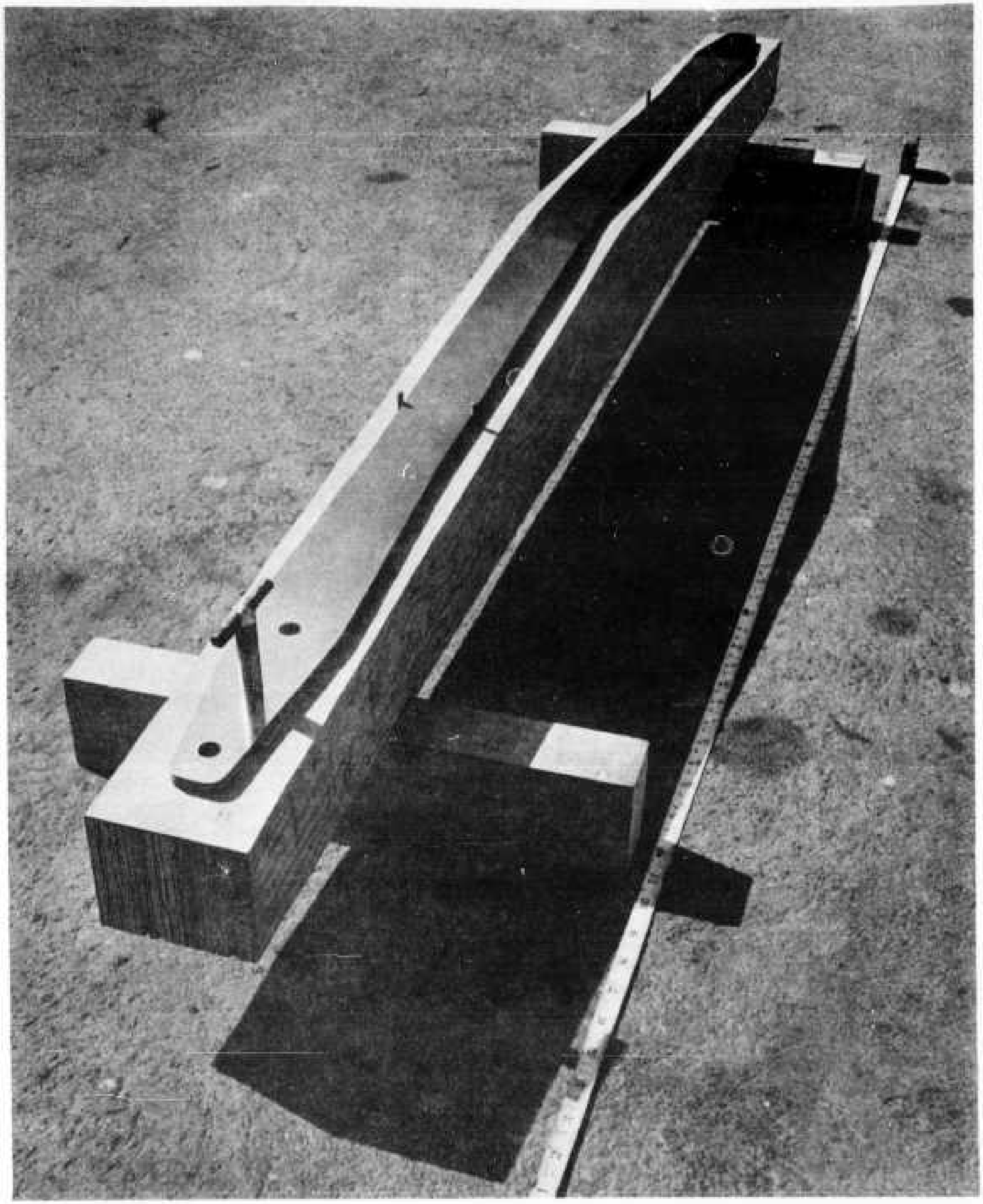

Figure 3. 1.6-1. Blade Retention Straps Ready for Bonding

3.1.7 Cascade Assembly - Drawing No. 285-0172

This cascade, shown in Figures 3.1.7-1 and 3.1.7-2 is mounted at the tip of the blade by anchor nuts. This assembly requires accurately formed aerodynamic turning vanes mounted within a supporting duct. It must be strong and stable under loads associated with an acceleration of 580g at 1200°F. To minimize weight, the part is made from Haynes 25 (AMS 5537-A) cobalt base alloy sheet, formed and joined by heliarc and spot welding. Conventional production forming tools would be applicable to all the detail elements, but since only three assemblies were needed for the whirl test, all parts but the vanes were shaped with hand tools and simple form blocks.

The good welding properties of the Haynes Alloy 25 cobalt base material resulted in a weldment with negligible distortion. Copper chill blocks were initially fabricated for welding the vanes in place, but were found impractical and unnecessary except in a few areas. The vanes were inserted through matching holes in the duct surfaces and welded on the outside. Haynes Alloy 25 welding rod was used. Anchor nuts were installed by projection welding. Inspection was by dye penetrant methods.

Following complete weld assembly, the entire unit was stress relieved at 1200°F for one hour. Afterwards, small undesirable air passages were sealed with Sauereisen Cement No. 31.

3.1.8 Hub Shaft and Spoke Assembly - Drawing No. 285-0534

This assembly consists of two parts, a shaft and a piece consisting of an inner ring and three radial spokes, shown assembled in Figure 3.1.8-1.

The shaft, HTC-AD Drawing No. 285-0517, was machined from 4340 steel tubing six inches in diameter with a wall thickness of 0.50 inch. It is heat treated to Rockwell C 32 to 40 (142,000 - 180,000 psi) prior to precision machining. The spoke piece, Drawing No. 285-0515 was rough machined from a hand forging of 4340 steel, heat treated to Rockwell C 32 to 36 (142,000 - 160,000 psi), and final machined to blueprint tolerances. Quality Control of the spoke included a piece of the parent metal to be heat treated at the same time as the spoke, and then tested to determine mechanical properties. Machining of both parts proved relatively conventional.

To produce a rigid connection between the shaft and spoke, a net fit exists between the two parts; therefore, assembly is made by chilling the shaft with dry ice and heating the spoke piece to approximately 500°F. In

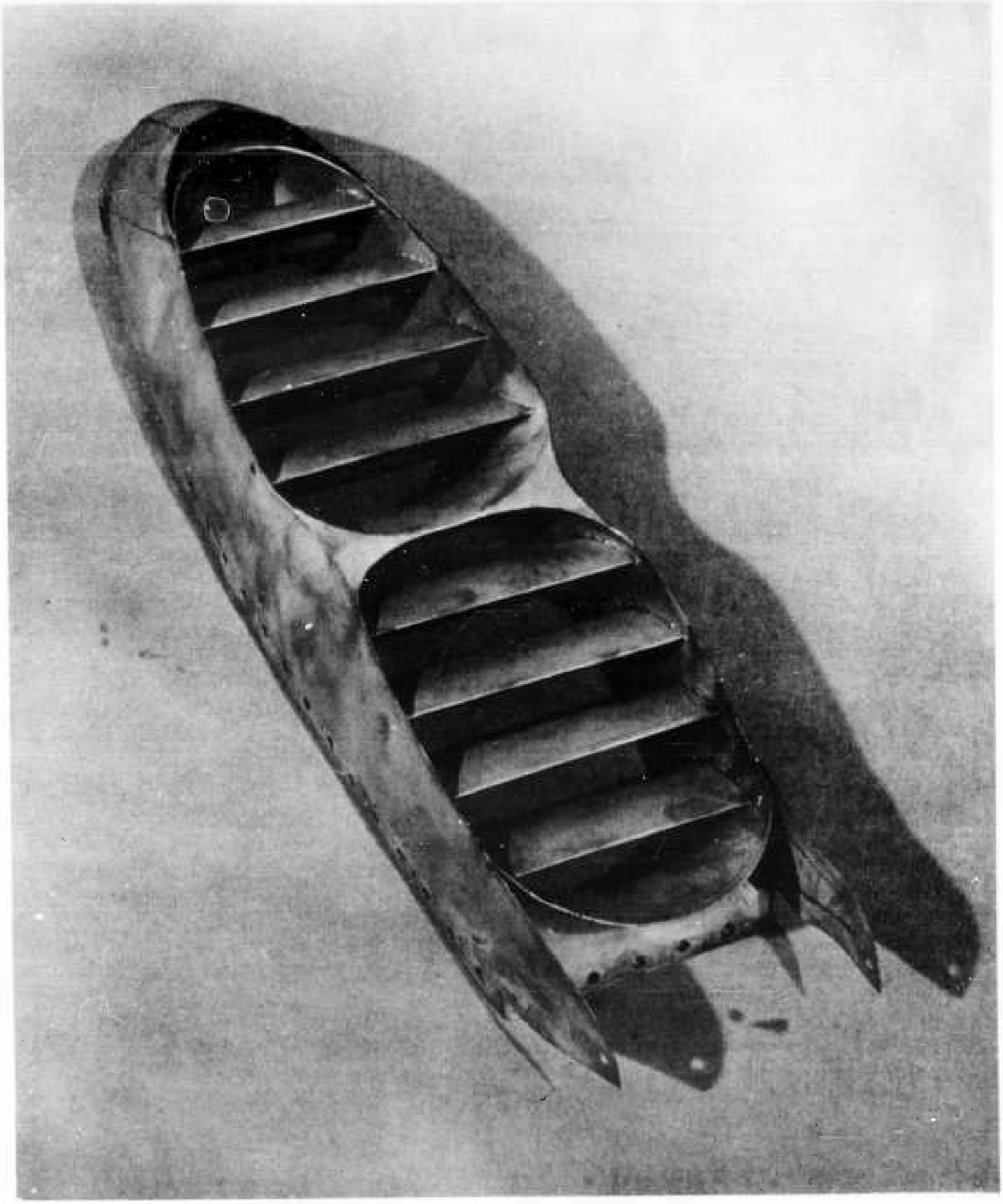

Figure 3. 1. 7-1. Completed Tip Cascade (External View)

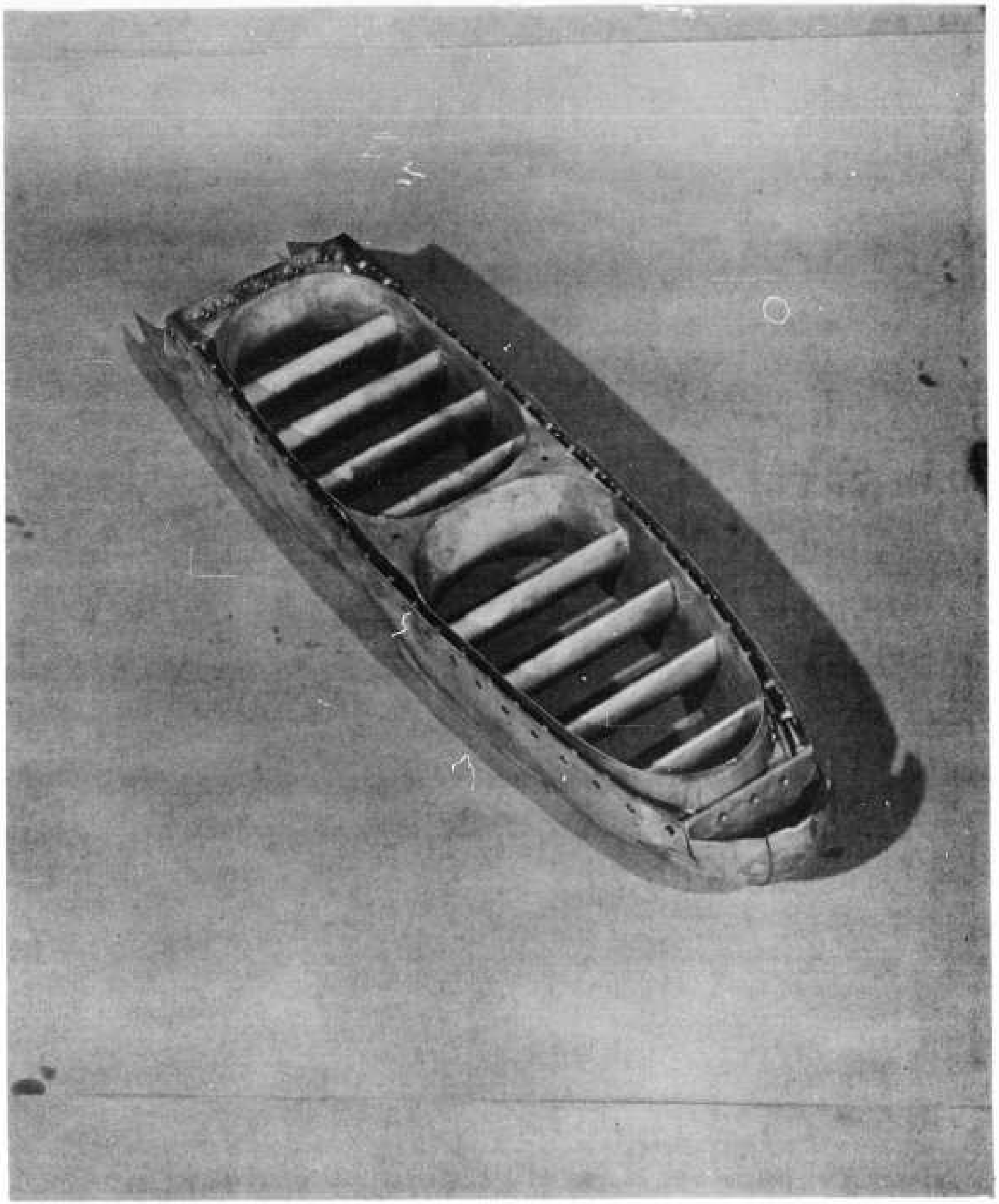

Figure 3. 1. 7-2. Complete Tip Cascade (Internal View)

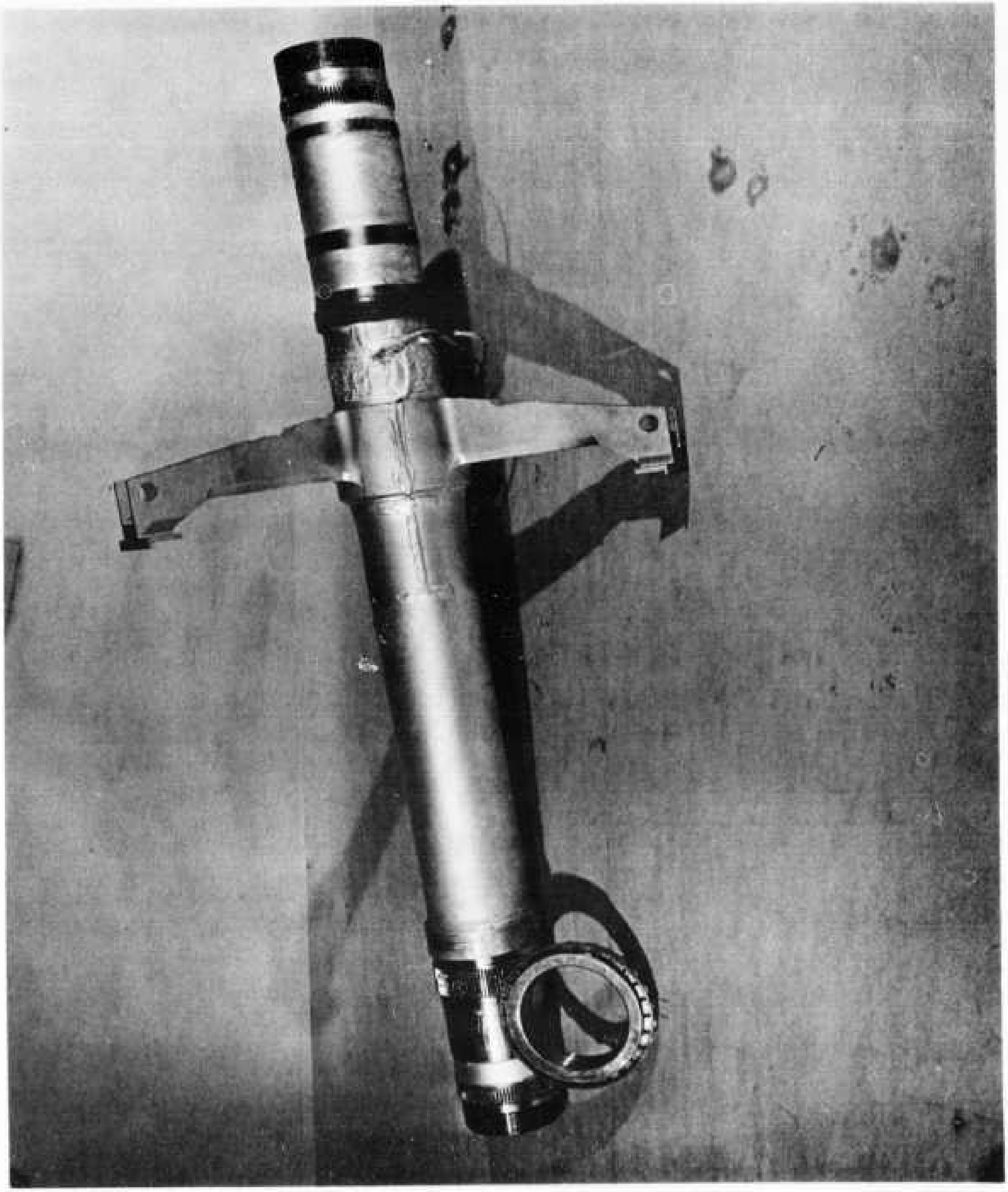

Figure 3. 1. 8-1. Shaft Spoke Assembly

order to provide acceptable alignment and concentricity of the large bearing supported by the spokes, the outer bearing surface and flange of the three spokes were machined after assembly of the spoke to the shaft.

3.1.9 Hub and Blade Duct Heat Shields - Drawing Nos. 285-0202 and 0590

The shields, made of .005 inch thick rigidised Aliron (1) surround the lower and upper hub ducts, and the blade root ducts. It is made from .004 inch thick steel clad on both sides with .0005 aluminum and rigidized (2) by roll pressing into a waffle pattern.

The sheets may be cut to proper size with hand shears, and readily hand formed. It may be attached to itself or to structure by numerous methods such as stapling, tying, or poke welding. Refer to Figure 3.1.9-1.

3.2 MAJOR SUB-ASSEMBLIES

3.2.1 Blade Assembly, HTC-AD - Drawing No. 285-0100

The blade consists of an assembly buildup of spars, ducts, cascades, fore and aft segments, and a feathering-flapping bearing, while the major structure of the blade consists of the foreward segments and the spars. Figures 3.2.1-1 and 3.2.1-2 show this assembly in process.

The segments were joined to each other in succession beginning at the root. Figure 3.2.1-3 shows an enlarge cross section of a typical joint. Assembly was initiated by first installing a flexural coupling into the inboard end of each segment, and then mating this sub-assembly to the one just inboard. Steel shims were used to facilitate sliding the shims and ducts of one segment past those of the adjoining one.

Attachment was done with flush head blind monel rivets. This necessitated pre-fitting, removal and dimpling of each riveted layer; followed by cleaning and final assembly. As can be seen in Figure 3.2.1-3, a sealant was required in the faying surfaces of the riveted joint and at the four corners of the adjacent ribs. This sealant, Dow Corning RTV 601, can be applied as a thin paste and is air vulcanizing at room temperature.

(1) Texas Instrument Co., Attleboro, Mass.
(2) Rigid Texas Metals, Buffalo, New York

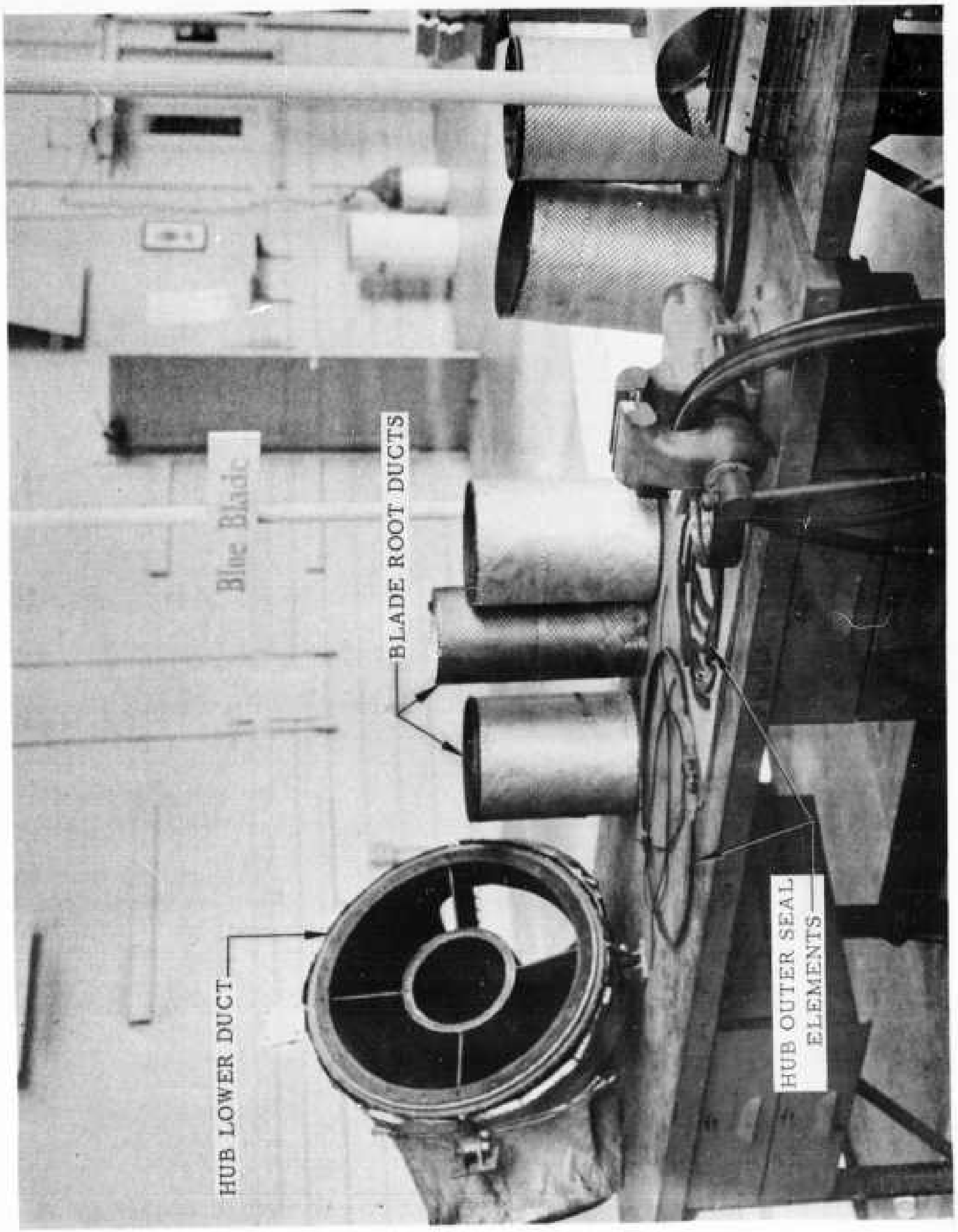

Figure 3.1.9-1. Heat Shields on Hub Lower Duct and Blade Root Ducts

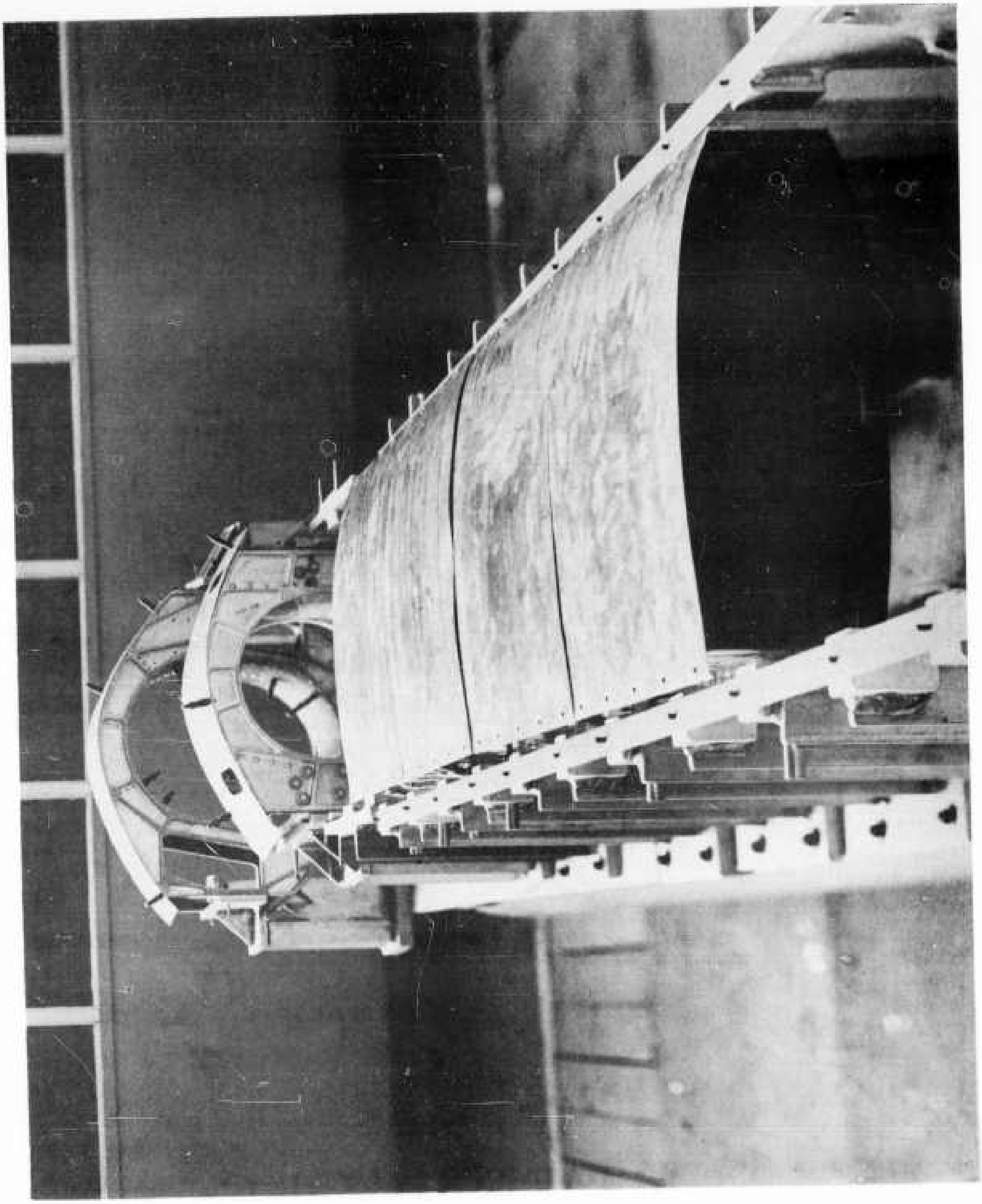

Figure 3.2.1-1. Initiation of Blade Assembly (seen from tip end)

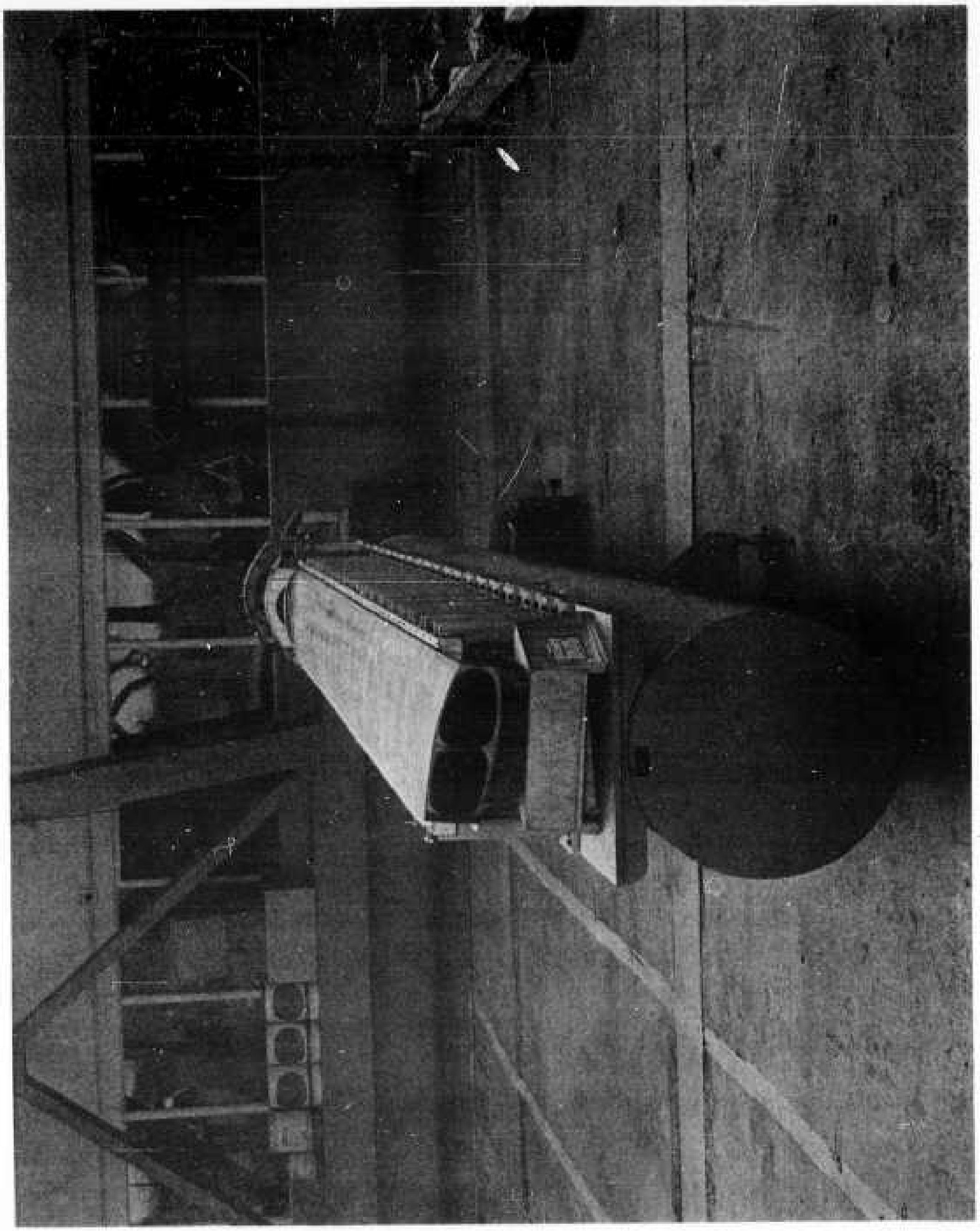

Figure 3.2.1-2. Blade Assembly Nearing Completion

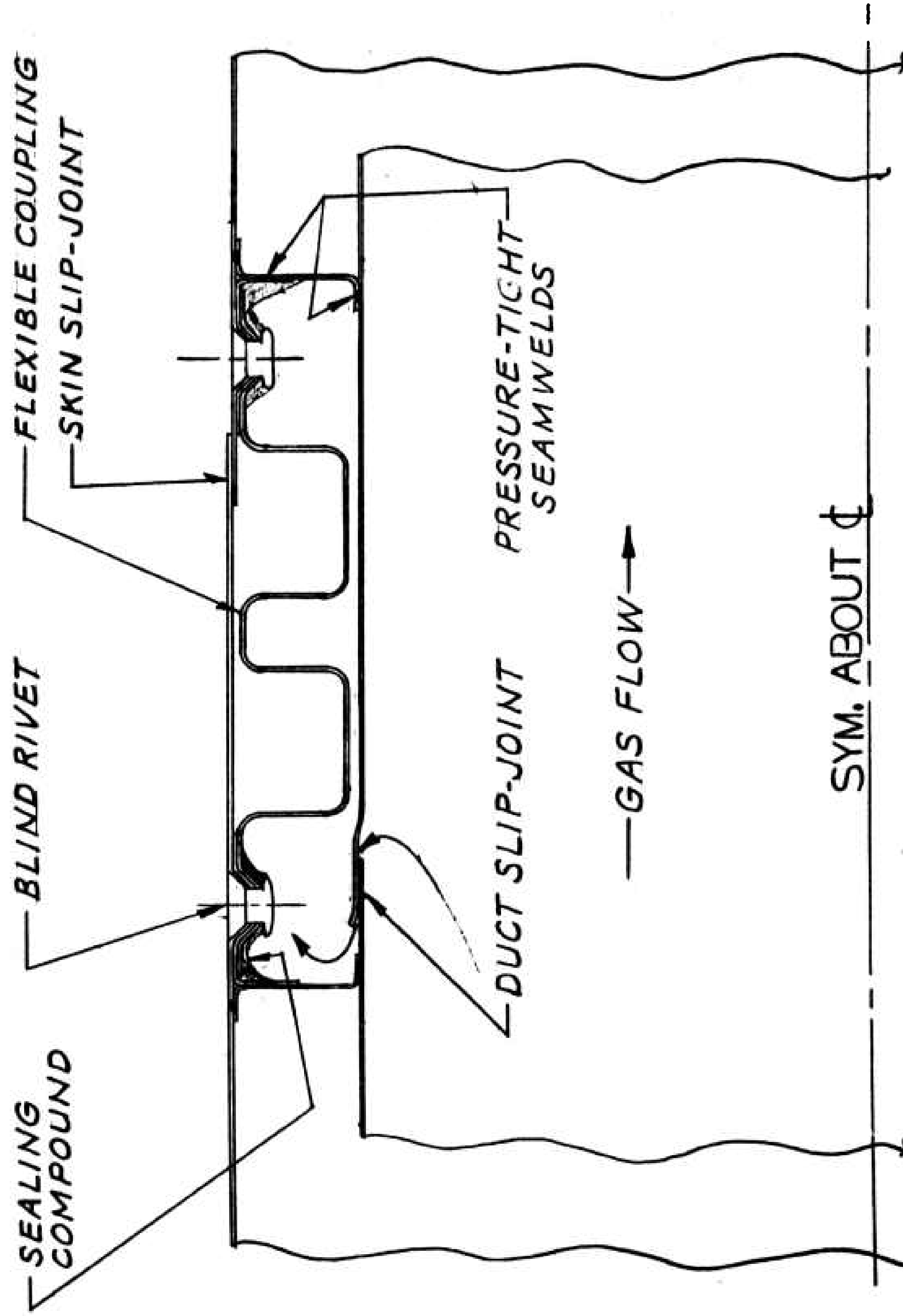

Figure 3.2.1-3 Typical Blade Segment Joint

Since the proper "twist" had been welded into the segments (refer to Section 3. 1. 2) and the jig was constructed to accomodate this (refer to Figure 3. 2. 1-2), the finished blade incorporated the twist without induced torsional stresses.

The root structure assembly follows conventional aircraft practices. Following the above effort, the jig forward locaters were removed and the forward spar was bolted to the segments and root structure. Finally the jig rear locaters were removed and the rear spar was bolted in place. At this time, the assembly was free of the jig, and the leading and trailing edge fairings, and the tip cascade could be attached by their respective screws.

3. 2. 2 Free-Floating Hub, HTC-AD - Drawing No. 285-0511

This hub, shown in process of assembly in Figure 3. 2. 2-1 is a bolted and welded assembly of machined components. All parts are machined from 4130 and 4340 steel, and in general, size and nature of machining are fairly conventional.

3. 2. 3 Ducts

3. 2. 3. 1 General

The hub and blade root ducts in general consist of short sections joined by V-band couplings. Each duct, therefore, has a machined ring with a tapered flange. The cylindrical ducts are rolled from .012 sheet and double seamwelded at the longitudinal lap joint. The circumferential joint to the flange was done with a row of spotwelds and one seamweld.

The hub upper and lower ducts, (HTC Drawing Nos. 285-0519 and 285-0522) because of compound curvatures, were drop-hammer formed of .062 sheet. Figure 3. 2. 3-1 shows the 285-0519 upper duct in process. This duct is a "Y" configuration with one main duct radiating equilaterally to match the three blade ducts. The formed sheet, machined flanges, and stiffeners are fusion welded in a jig.

These ducts are intended for operation at approximately 1200°F and it was believed warpage during the initial operation would prevent reassembly after tear-down. All of the above ducts were therefore, stress relieved after assembly at 1175 ± 25°F for 30 minutes. In all cases relatively massive stress relief fixtures of Type 321 or 347 corrosion resistant steel were utilized; and these in turn were stress relieved prior to machining,of the final matching surfaces.

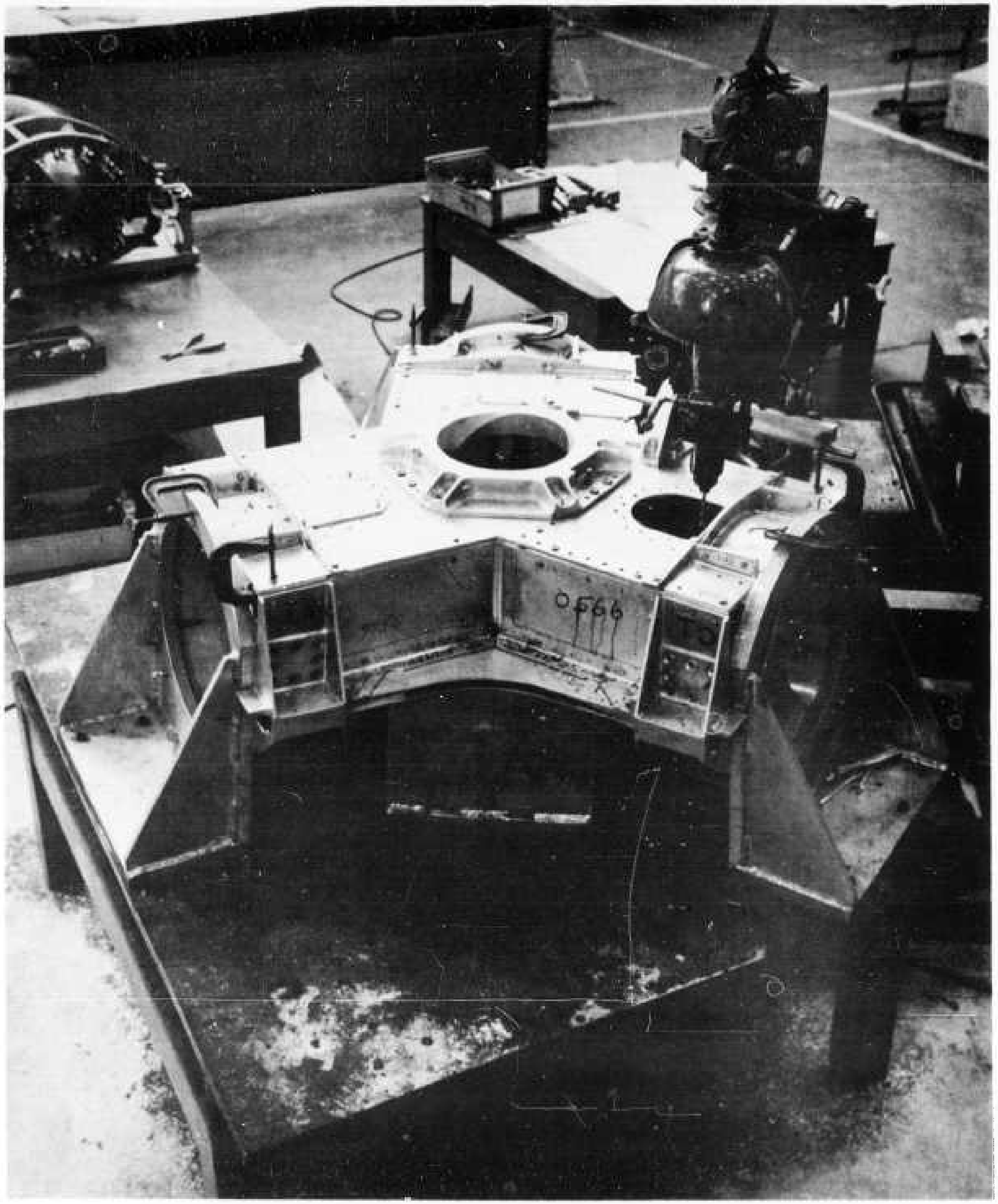

Figure 3.2.2-1. Floating Hub in Process of Assembly

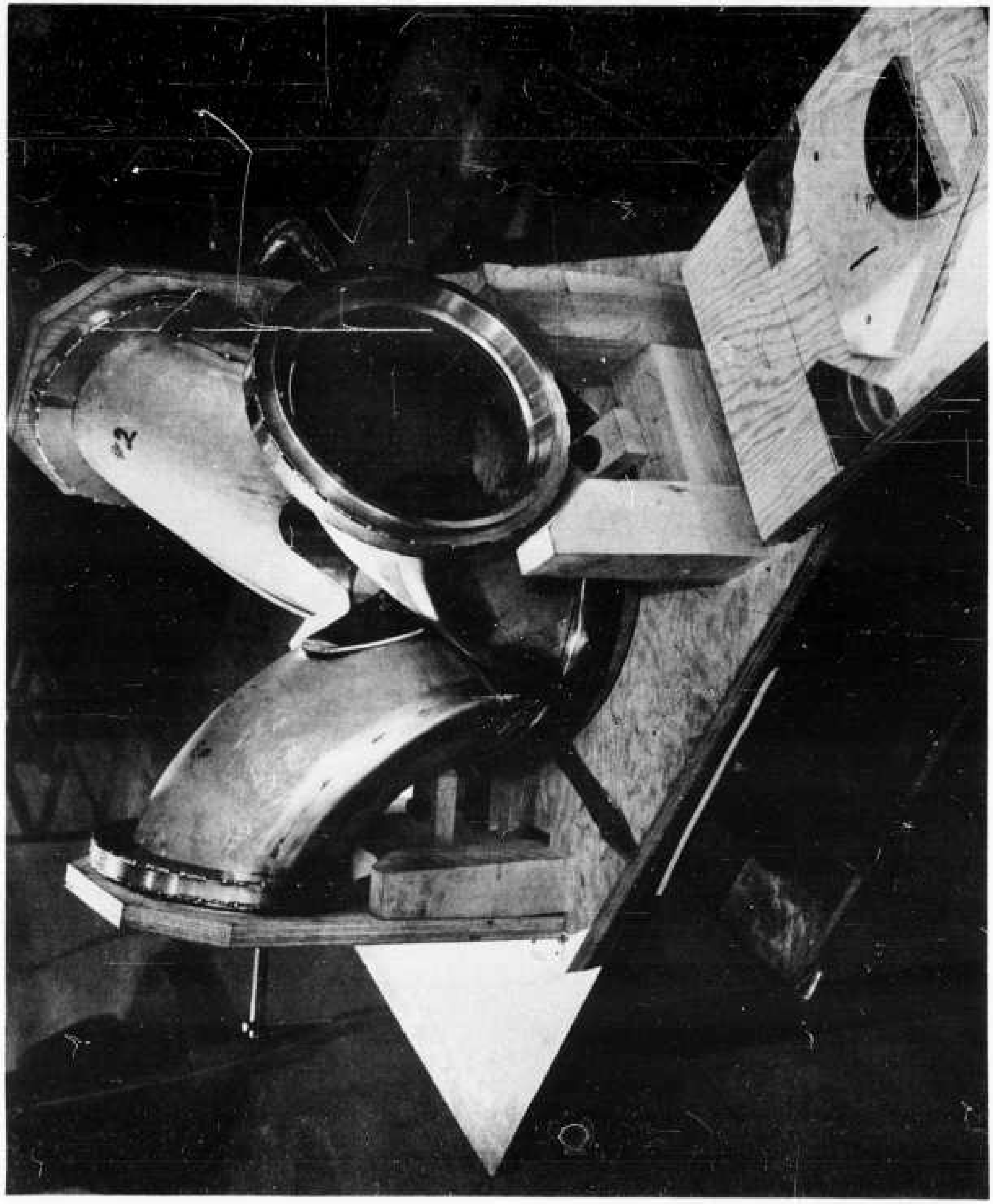

Figure 3.2.3-1. Hub Upper Duct Assembly in Process

Because of the relatively low short- and long-time strengths of the Type 321 and 347 corrosion resistant steels, experience has indicated these materials are too unstable for use where maintenance of dimension is important for mating of two or more components. Future efforts should reflect this experience.

3.2.3.2 Transition Duct - Drawing No. 285-0132

This duct, shown in Figure 3.2.3-2 is a "Y" configuration which accepts gases in one duct and directs them to two smaller ducts. The entire assembly, except for a Type 347 ring flange, is made from Inconel X. The ducts are drop-hammer formed and the frames hand-formed over blocks. The method of assembly is by spotwelding, readily observed in Figure 3.2.3-2.

Following complete assembly, except for installation of the Type 347 corrosion resistant ring flange, the duct was stress relieved and heat treated at 1625°F for 30 minutes and forced air cooled to room temperature. It was then aged at 1300 ± 25°F for 20 hours. Following this the ring flange was installed, and the entire assembly stress relieved at 1150 ± 1200°F for 30 minutes, furnace cooled to 900°F and air cooled to room temperature.

3.3 FINAL ASSEMBLY - DRAWING NO. 285-0004

The rotor consists of the final assemblies of the three blades, the complete hub structure and the control system. Figure 3.3-1 shows the initiation of the hub structural assembly and Figure 3.3-2 shows the hub structure and the control system in the final assembly stages. Figure 3.3-3 shows the completed rotor assembly.

All assembly is by means of conventional aircraft type bolts and nuts. The hub shaft main upper and lower nuts were lubricated with Shell Darina AX. and torqued (approximately 5200 - 5600 ft./lbs.) to produce a strain-gage measured tensile force of 60,000 ± 4000 lbs in the shaft.

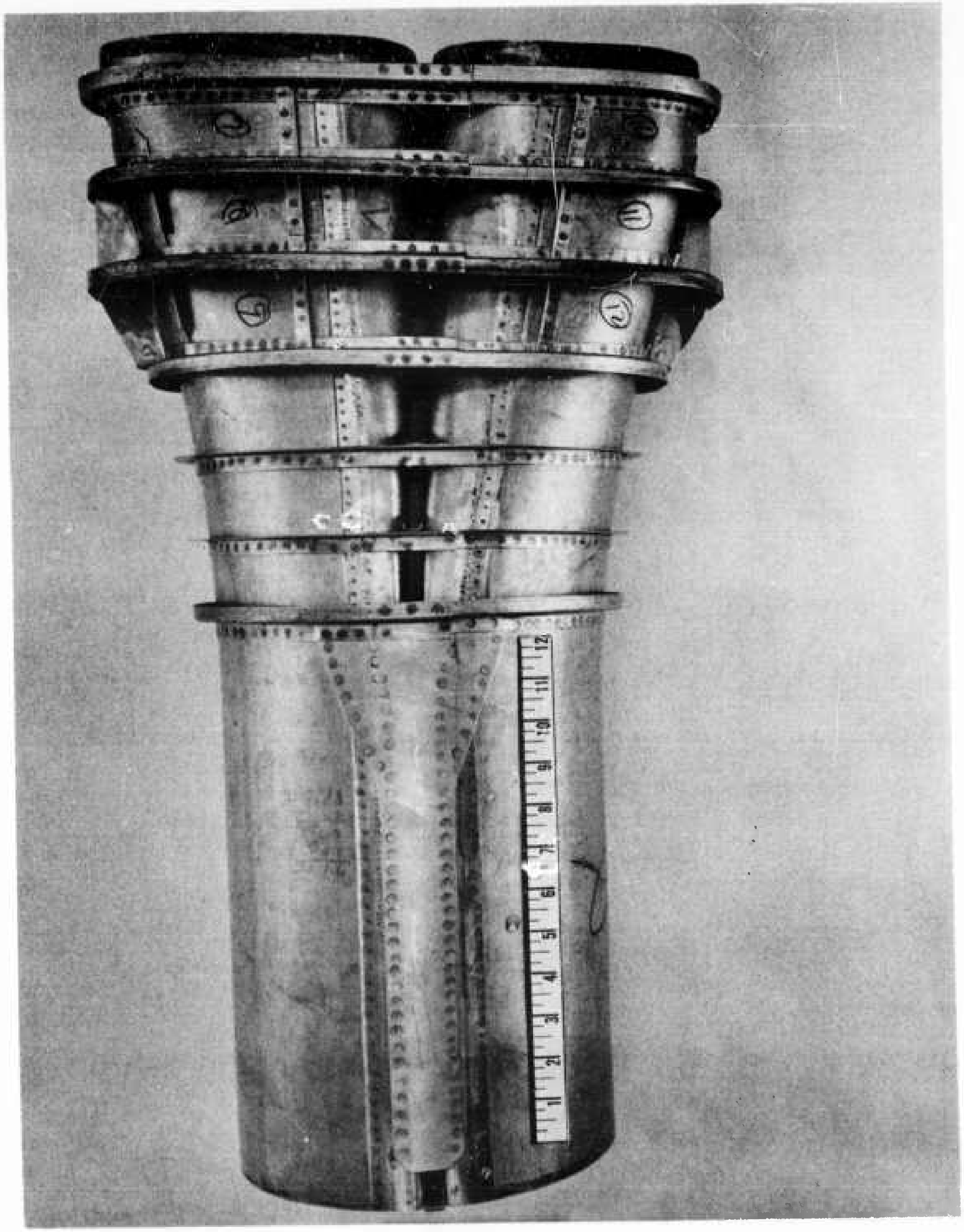

Figure 3. 2. 3-2. Blade Duct Transition (Inconel X)

Figure 3. 3-1. Initiation of Hub Assembly

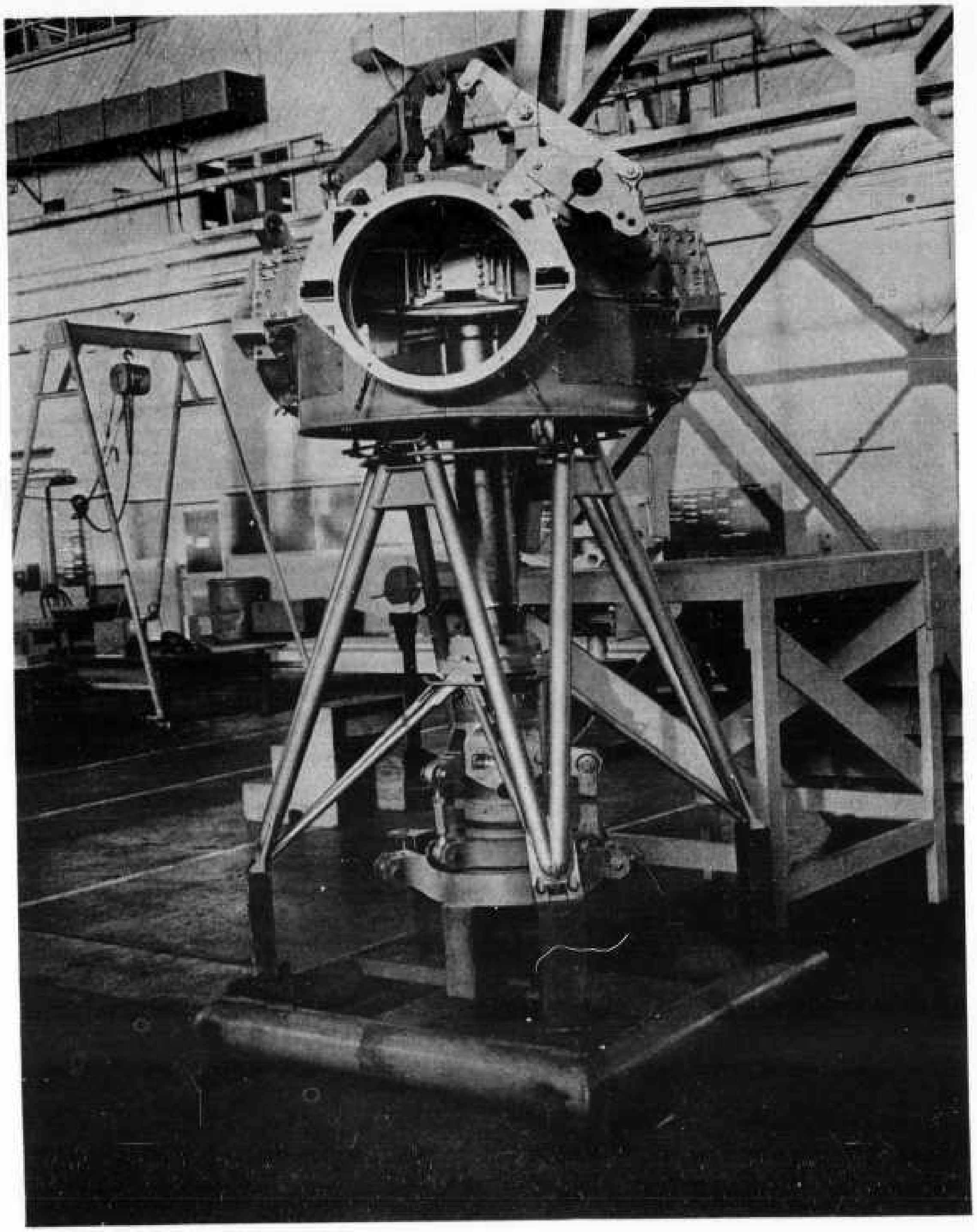

Figure 3.3-2. Hub and Control System Assembly (Less Ducts)

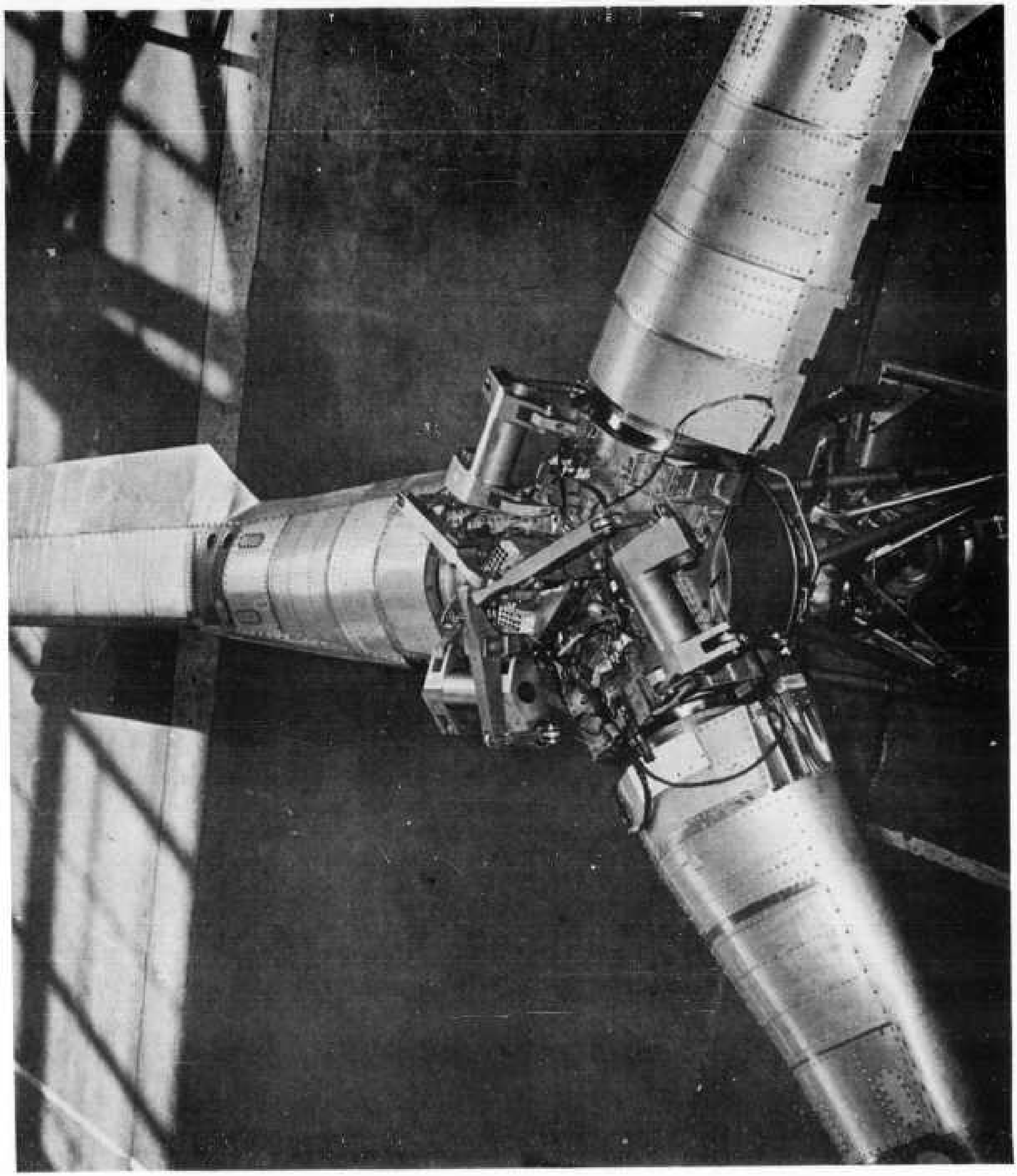

Figure 3. 3-3. Completed Rotor System Assembly

SECTION 4

TEST MACHINES

4.1 WHIRL TOWER

The whirl tower, shown at the beginning of the report in Figure 1-1, is of the conventionally welded low carbon "I" beam and pipe. It is secured to the ground by steel bolts imbedded in steel reinforced concrete caissons. The tower can be removed from the site intact by removal of the nuts on the anchor bolts passing through the ground level "I" beams. Further information concerning design of the whirl tower and its supporting equipment can be gained from Reference 3.

4.2 FATIGUE MACHINE

The fatigue machine, as shown in Figure 4.2-1 is not unlike a long bed lathe in appearance. It was used as a test jig for the Full-Scale Blade Specimen Fatigue Test.

The machine is a conventional arc-welded assembly of low carbon steel plate, pipe and "I" beams. It is firmly secured by bolts and plates anchored in steel reinforced concrete caissons and can be disconnected from the caissons by removal of the nuts. See Reference 4 for design information.

4.3 MISCELLANEOUS TEST MACHINES

There exist several small test machines used for material tests, seal development tests, and fatigue tests. All are conventional welded type structures of low carbon steel. Details regarding design of these machines are covered in Reference 4.

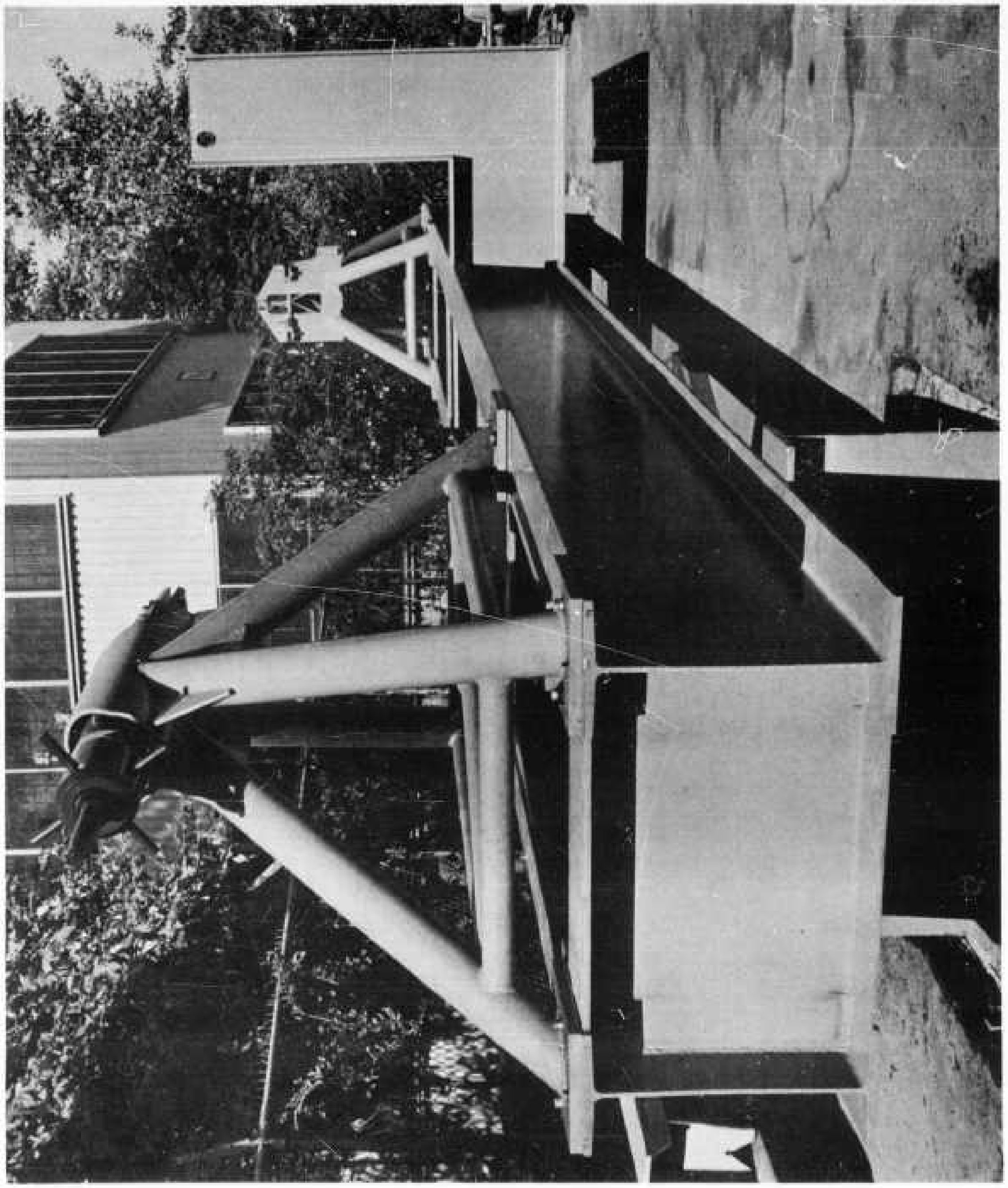

Figure 4.2-1. Full-Scale Blade Fatigue Test Machine

SECTION 5

FABRICATION OF JIGS AND FIXTURES

5.1 GENERAL

There are four jigs which are worthy of mention. Two of these are temporary types made of wood and used for building up the lower (stationary) and upper (rotating) hub ducts. A third jig is permanent, very rigid and accurately made and is used for the final assembly of the blade. The fourth jig also is permanent, very rigid, and accurately made; used for the final assembly of the free-floating hub. All other tooling falls into the fixture category as helpful aids and small complementary fixtures for standard machine tools. They were conceived and fabricated "on the job" as needed by the mechanic.

5.1.1 Lower Stationary Duct Welding Jig

The lower stationary duct welding jig is made of wood. It incorporates two swinging faces which are hung by piano hinges. These faces locate and hold the joint flanges for welding. Welding clamps position and secure the largest flange for welding. Figure 5-1 shows this jig in use for the weld assembly of the lower duct.

5.1.2 Upper Rotating Duct Welding Jig

This jig is the same as that noted in the preceeding paragraph except that it incorporates three swinging faces instead of two. The previous Figure 3.2.3-1 shows this jig in use for the assembly of the upper rotating duct weld assembly.

5.1.3 Blade Final Assembly Jig

This jig, shown in Figure 5-2, is used for the final assembly of the blade. Rigidity is obtained by use, as a base, of a large diameter tube to which a thick plate has been welded. Brackets support the blade segments and incorporate the desired blade twist. They retain the segments in position during riveting. The brackets are made removable to allow installation of the spar on one side at a time.

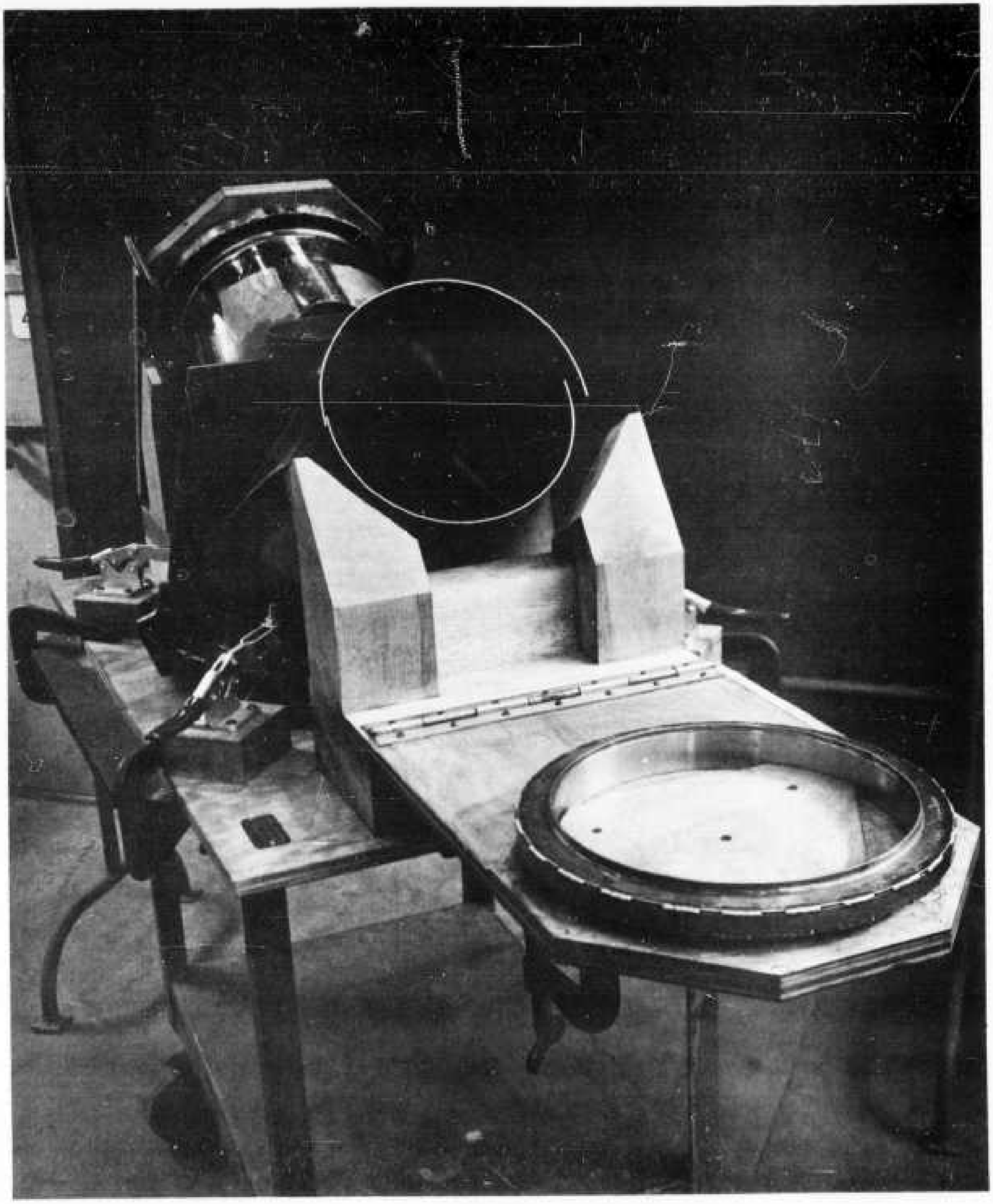

Figure 5-1. Hub Lower Duct Assembly Jig

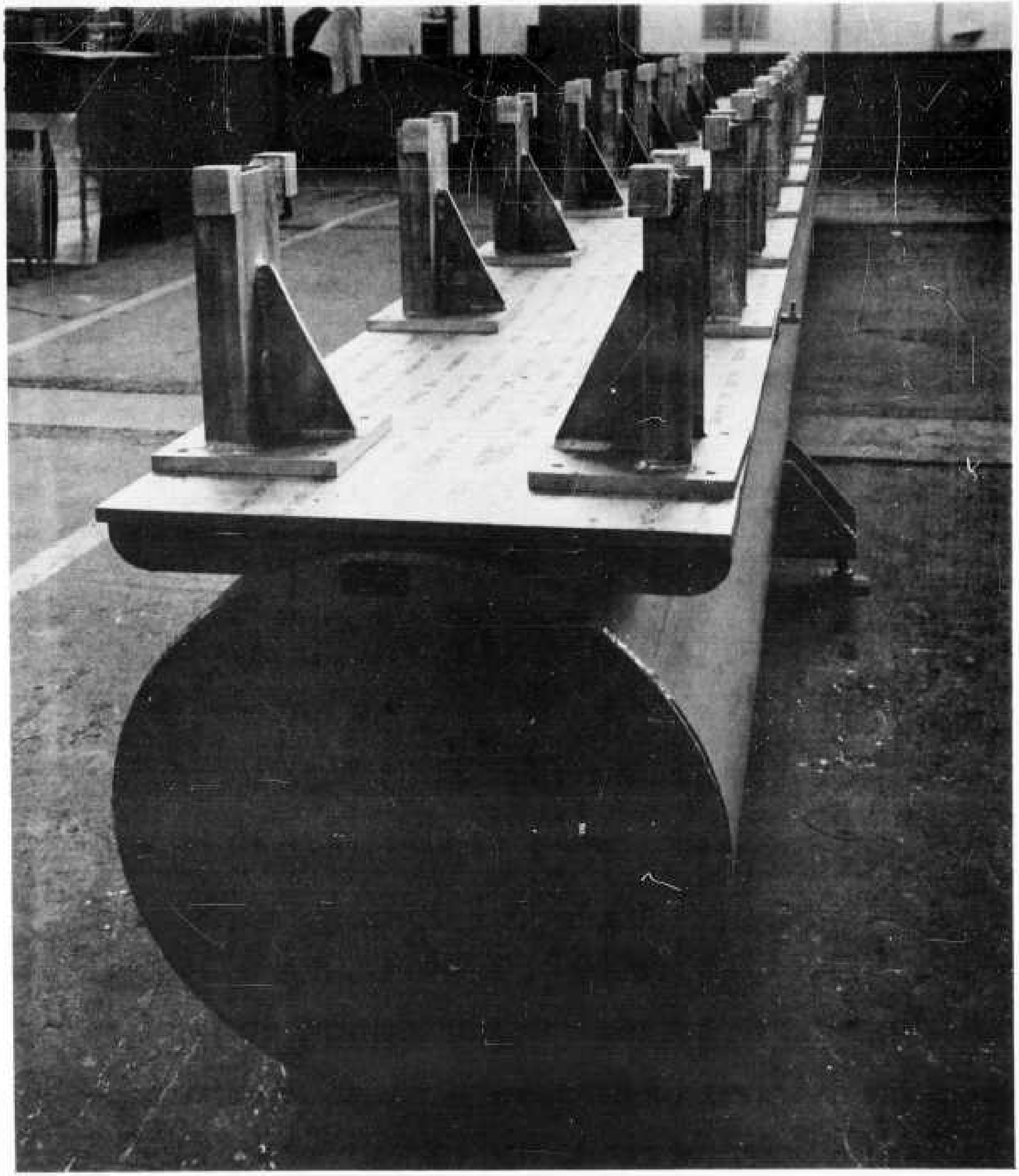

Figure 5-2. Blade Final Assembly Jig

5.1.4 Free-Floating Hub Final Assembly Jig

This jig, used for the final assembly of the floating hub, is shown in Figure 5-3 during the initial step of floating hub assembly. It consists of a heavy steel plate to which is bolted machined, gusseted, and welded aluminum brackets and supports for positioning the various floating hub detail parts.

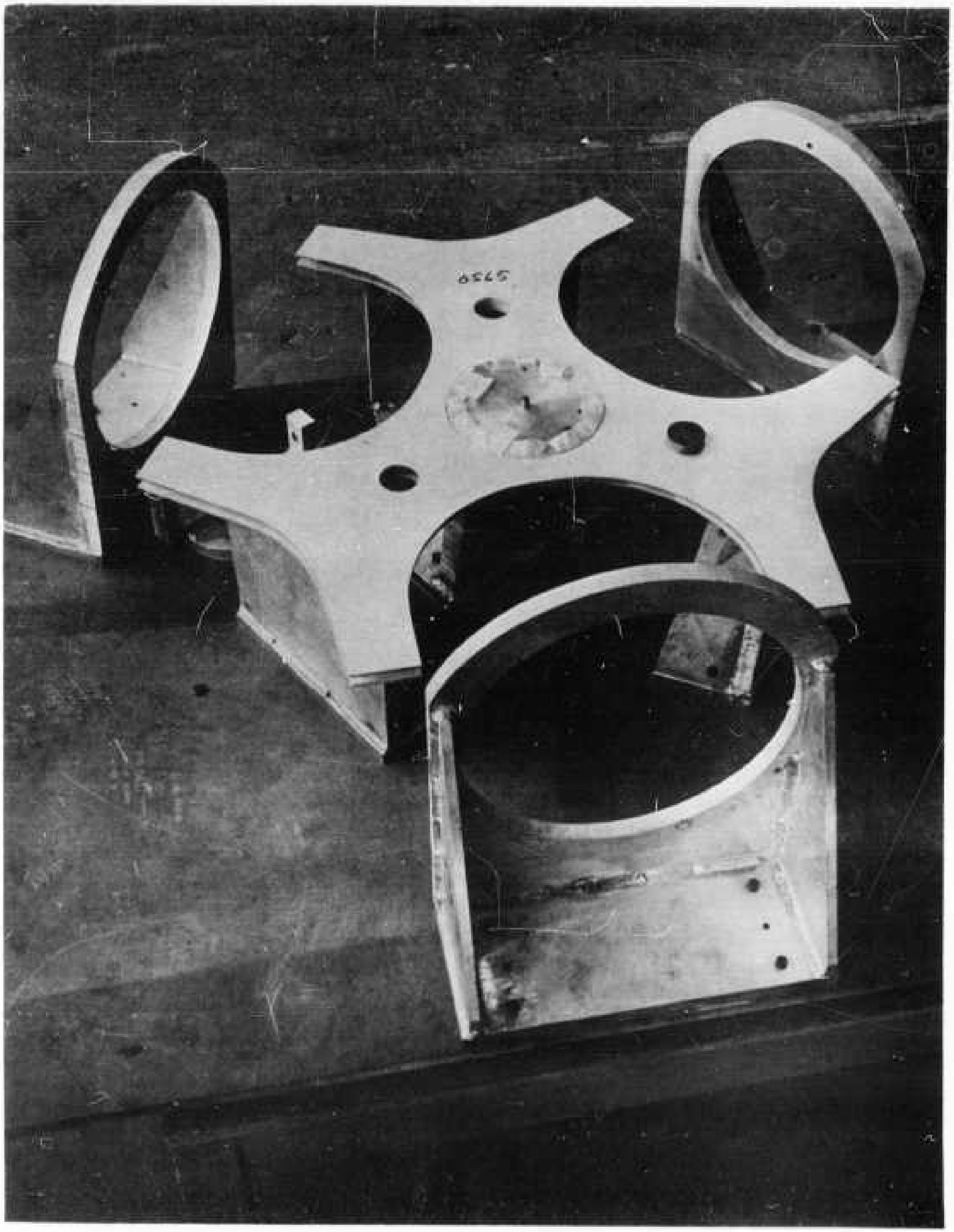

Figure 5-3. Floating Hub Assembly Jig

SECTION 6

REFERENCES

1. Plowe, O. I. and Sallows, S. E.; "Hot Cycle Rotor System, Design of Rotor," HTC-AD Report No. 285-12 (62-12); March 1962.

2. French, J. C.; "Hot Cycle Rotor System, Materials and Processes," HTC-AD Report No. 285-18 (62-18) March 1962.

3. Amer, K. B.; "Hot Cycle Rotor System, Whirl Tests," HTC-AD Report No. 285-16 (62-16); March 1962.

4. Smith, C. R.; "Results of Component Test Program, Final Report," HTC-AD Report No. 285-9-8 (62-8); March 1962.

SECTION 7

APPENDIX

The following table is a complete list of all drawings released for fabrication of the Hot Cycle Rotor. Titles are offset to indicate relative assembly magnitude and the general detail requirements for subassemblies and the final assembly.

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TABLE NO. 1

HOT CYCLE ROTOR SYSTEM DRAWINGS

DRAWING NO.	TITLE
285-0004	Test Installation - Hot Cycle Whirl
285-0005	Rotor Assembly - Hot Cycle
285-0100	Blade Assembly - Hot Cycle Main Rotor
285-0171	Tip Assembly - H.C.R.B. Forward
285-0172	Cascade Assembly - H.C.R.B. Forward
285-0173	Tip Assembly - H.C.R.B. Aft
285-0187	Fairing - Blade Tip Aft
285-0117	Segment Assembly - H.C.R.B. Aft
285-0167	Segment Installation - H.C.R.B. Forward
285-0113	Segment Assembly - H.C.R.B. Forward
285-0114	Rib - H.C.R.B. Forward
285-0191	Shield Installation - Forward Segment
285-0165	Coupling Assembly - H.C.R.B. Segment Flexure
285-0193	Flexure - Forward Segment Coupling
285-0203	Coupling Assembly - Wrought
285-0199	Flexure Assembly
285-0138	Structure Installation - H.C.R.B. Station 74.00 to 91.00
285-0139	Structure Installation - H.C.R.B. Station 63.00 to 73.00
285-0128	Rib - H.C.R.B. Station 63.00
285-0129	Rib - H.C.R.B. Station 73.00
285-0163	Fitting - H.C.R.B. Strap Attach Front Spar
285-0164	Fitting - H.C.R.B. Strap Attach Rear Spar
285-0159	Duct Installation - H.C.R.B. Station 15.50 to 92.00
285-0228	Clamp Fitting - Duct Joining
285-0160	Duct Assembly - Inboard Articulated
285-0180	Housing Assembly - Inboard Articulated Duct Seal
285-0178	Ring Assembly - Duct Gimbal
285-0179	Duct Assembly - Inboard Articulated Sta. 15.50 to 37[illegible]
285-0131	Bracket - Articulated Duct Support
285-0175	Ball Assembly - Articulated Duct
285-0218	Fail Safe Instal. - Articulate Duct Gimbal
285-0194	Turnbuckle Assembly
285-0137	Duct Assembly - Station 49.00 to 60.50
285-0141	Clamp - Duct Joining
285-0136	Ring - H.C.R.B. Duct
285-0196	Clevis - Outboard Duct Hold Back
285-0195	Duct Assembly - Station 88.06 to 91.93
285-0162	Housing Instal. - Articulate Duct Outboard Seal
285-0156	Segments - Articulate Duct Outboard Seal
285-0181	Housing Assy. - Articulate Duct Outboard Seal
285-0168	Fitting - Outboard Articulate Duct
285-0182	Fittings - Outboard Articulate Duct Support
285-0169	Spring - Outboard Articulate Duct Garter
285-0161	Ring - Outboard Articulate Duct

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DRAWING NO.	TITLE
285-0185	Spring - Outboard Articulate Duct Press
285-0186	Spring - Outboard Articulate Duct Retainer
285-0204	Modification Drawing - Articulate Duct Seal
285-0217	Clip Seal Assembly - Nested
285-0132	Duct Assembly - H.C.R.B. Transition
285-0166	Structure Instal. - H.C.R.B. Station 33.00 to 63.00
285-0197	Frames - Flexure Station 34.75, 45.25 and 61.75
285-0127	Structure Instal. - H.C.R.B. Station 25.00 to 33.00
285-0135	Rib - H.C.R.B. Station 33.25
285-0140	Arm Assembly - H.C.R.B. Feathering
285-0126	Ball - H.C.R.B. Feathering Bearing
285-0176	Fitting - H.C.R.B. Station 25.25 to 33.25
285-0190	Rib Assembly - H.C.R.B. Station 24.25
285-0189	Rib Segment - H.C.R.B. Station 24.25
285-0134	Rib - H.C.R.B. Station 24.25
285-0121	Strap Assembly - Hot Cycle Main Rotor Blade
285-0170	Spars - Hot Cycle Main Rotor Blade
285-0155	Bearing Assembly - H.C.R.B. Fabric Feathering
285-0133	Droop Stop Installation - H.C.R.B.
285-0183	Bearing - Droop Stop
285-0223	Doubler Installation - Rear Spar Station 73.00
285-0222	Yoke - Rear Spar Station 73.00
285-0221	Filler - Rear Spar Station 73.00
285-0220	Doubler - Rear Spar Station 73.00
285-0123	Fairing Installation - H.C.R.B. Outboard Nose
285-0124	Fairing Installation - H.C.R.B. Inboard Nose
285-0125	Fairing Installation - H.C.R.B. Inboard Aft
285-0202	Heat Shield - Station 19 to 91 Inboard Duct
285-0198	Shim - Anti-Fretting
285-0300	Controls Installation - HCR Upper Flight
285-0327	Spindle and Support Assembly - Lower Hub Controls
285-0308	Support Assembly - Lower Controls
285-0309	Billet - Lower Support Assembly
285-0311	Mounting Details - Spindle and Slip Ring
285-0335	Drive Link Assembly - Rotor Swashplate
285-0326	Bearings (Reference)
285-0336	Link Assembly - Rotation Swashplate
285-0326	Bearings (Reference)
285-0318	Collar Assembly - Lower Support
285-0312	Swashplate Details - Rotating
285-0325	Billet - Rotating Swashplate
285-0313	Swashplate Details - Stationary
285-0338	Billet - Stationary Swashplate
285-0332	Drag Link Assembly - Stationary Swashplate
285-0326	Bearings (Reference)
285-0316	Centering Bearing Assembly - H.C.R. Swashplate
285-0315	Centering Bearing Cup - H.C.R. Swashplate

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DRAWING NO.	TITLE
285-0314	Centering Bearing Ball - H.C.R. Swashplate
285-0310	Small Parts Details - Control System
285-0307	Control Rod Assembly - Center
285-0326	Bearings - Control System H.C.R.
285-0306	Support Assembly - Control System Upper
285-0305	Control Rod Assembly - Upper Hub
285-0326	Bearings (Reference)
285-0306	Support Assembly - Control System Upper
285-0305	Control Rod Assembly - Upper Hub
285-0326	Bearings (Reference)
285-0303	Torque Tube Assembly - Upper Hub Control
285-0328	Details - Controls Torque Tube Assembly
285-0329	Billet - Torque Tube Assembly
285-0330	Inboard Support - Torque Tube Assembly
285-0331	Outboard Support - Torque Tube Assembly
285-0500	Hub Installation - Hot Cycle Rotor
285-0511	Hub Assembly - Hot Cycle Rotor Tilting
285-0574	Housing Assembly - H.C.H. Feathering Bearing
285-0512	Plate - H.C.H. Droop Stop
285-05[illegible]	Shoe - H.C.H. Strap
285-0[illegible]	Ring - H.C.H. Tilting
285-0[illegible]	Billet - H.C.H. Feathering Bearing Ring
285-0[illegible]	Angle - H.C.H. Shoe Bracket Attachment
285-05[illegible]	Fitting - H.C.H. Beam Intersection
285-0560	Billet - H.C.H. Beam Intersection Fitting
285-0563	Fitting - H.C.H. Splice
285-0564	Plate - H.C.H. Strap Lower
285-0565	Plate - H.C.H. Strap Upper
285-0566	Web - H.C.H. Side
285-0567	Fitting - H.C.H. Beam Shoe Attach
285-0568	Plate - H.C.H. Tension Tie
285-0569	Cap - H.C.H. Upper Beam
285-0570	Angle - H.C.H. Beam Upper
285-0571	Fitting - H.C.H. Ring Shoe
285-0572	Plate - H.C.H. Tension
285-0573	Web Assembly - H.C.H. Upper
285-0575	Angle - H.C.H. Shoe Bracket Attach
285-0576	Bracket - H.C.H. Shoe to Ring
285-0578	Angle - H.C.H. Web Attach
285-0577	Stop Assembly - H.C.H. 1° Tilt
285-0579	Fitting - H.C.H. 1° Tilt Stop
285-0580	Counterbalance Assembly - H.C.H. 1° Tilt Stop
285-0581	Arm Assembly - H.C.H. 1° Tilt Stop
285-0582	Retainer - H.C.H. 1° Tilt Stop

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DRAWING NO.	TITLE
285-0583	Bracket - H.C.H. Closeout
285-0584	Spacer - H.C.H. Droop Stop
285-0514	Gimbal Assembly - Hot Cycle Hub
285-0527	Trunnion Shaft Assembly -HCRH Gimbal
285-0528	Ring Assembly - HCRH Gimbal
285-0529	Fitting - HCRH Gimbal
285-0561	Billet - HCH - Gimbal - Fretting
285-0530	Details - HCRH Gimbal
285-0534	Shaft Assembly - Hot Cycle Hub
285-0517	Shaft - Hot Cycle Hub
285-0515	Spoke - Hot Cycle Hub
285-0555	Blank - Spoke
285-0554	Washer - Radius
285-0552	Inner Ring Assembly - Hub Upper Bearing Housing
285-0553	Outer Ring - Hub Upper Bearing Housing
285-0516	Small Part Details - Hub Upper Bearing
285-0546	Roller Bearing - Rotor Shaft Upper Radial
285-0556	Seal - Hub Upper Support Bearing
285-0518	Spacer - H.C.R. Shaft
285-0524	H.C.R. Hub Thrust Bearing
285-0525	Shim - H.C. Hub
285-0541	Duct Installation - H.C. Hub, Upper
285-0519	Duct Assembly - Upper Rotating
285-0505	Ring - Hub Outer Seal Bearing
285-0540	Ring Assembly - Upper Duct Clamp
285-0588	Spacer and Link - H.C. Hub Upper Duct
285-0589	Block Assembly - Hub Upper Duct Insulator
285-0522	Duct Assembly - Lower Stationary
285-0509	Seals Installation - HCH
285-0141	Clamp (Reference)
285-0507	Gasket - Duct
C-102481-1	Housing
C-102481-2	Carbon Ring
C-102481-3	Carbon Assembly
C-102481-4	Garter Spring
C-102481-5	Coil Spring
C-102978	Face Seal Assembly
B-102979	Mating Ring
285-0533	Spacer - HC Thrust Bearing
285-0543	Sleeve - Hot Cycle Rotor Shaft
285-0585	Installation - H.C.H. Seal
285-0590	Insulation - Hub Ducts
285-0523	Mount Assembly - Hot Cycle Hub
285-0544	Fittings - Upper and Lower Truss